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A

TEXT-BOOK

ON

CHEMISTRY.

FOR THE USE OF

SCHOOLS AND COLLEGES.

BY

JOHN WILLIAM DRAPER, M.D.,

Professor of Chemistry in the University of New York, Member of the American Philosophical Society, &c.

With nearly Three Hundred Illustrations.

NEW EDITION.

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BY THE SAME AUTHOR.

A Text-Book on Natural Philosophy.

FOR THE USE OF SCHOOLS AND COLLEGES.

WITH NEARLY 400 ILLUSTRATIONS. 12MO, SHEEP, 75 CENTS.

PREFACE.

THIS text-book on Chemistry, intended for the use of colleges and schools, contains the outline of the course of Lectures which I give every year in this University.

I do not, therefore, present to teachers an untried work. Its divisions and arrangement are the result of an experience of several years; an experience which has proved to me that there is required a text-book of small size, so that students can pass through it readily in the time usually devoted to Chemistry.

Every instructor in this science must have observed that the ordinary "Treatises" or "Elements" are by no means suited to his wants. When they are employed in the class-room, there are large portions which have to be omitted, and other portions too briefly explained. In fact, to study Chemistry successfully, the first thing which is wanted is a compendious book, which sets forth in plain language the great features of the science, without perplexing the beginner with too much detail.

It will be understood, therefore, that this work, with little pretensions to originality, except where directly specified, occupies a different field from that of the larger treatises. It is intended as a manual, arranged in such divisions as practice has shown to be suitable for daily instruction. It is the exposition of what I have found to be a satisfactory method of teaching; and of its success our annual examinations are the best testimonial.

The unsuitableness of large text-books has led to many attempts to reduce their size by abstracts and compendiums; but the difficulty can never be avoided by that means; the very structure of such works is faulty. We never want to use all that an author knows or can possibly say on the subject. It has been well remarked, that "the greatest service which can be rendered to our science is for some person who has had the management of large classes for several years to sit down and write a book, setting forth what he said and what he did every day in his Lectures. That is the thing we want."

While, therefore, this book is offered to instructors as a practical work, the object of which is to display the leading features of the science, I have endeavored to make it a representation of the present state of Chemistry. In this respect many of our most popular works are defective. Among them I should not know where to turn for a simple exposition of the Wave theory of Light or of Ohm's theory of Voltaic Currents; yet the one is the most striking result of physical research, and the other is connected with the fundamental facts cf Electro-chemistry.

To the treatises of Hare, Kane, Graham, Gregory, Fownes, Dumas, and Millon I must formally state my obligations. In Descriptive Chemistry I have followed them closely; and in those cases which are much more common than is generally supposed, where there are differences in the imputed properties of bodies, I have consulted, wherever I could, either original memoirs or the annual reports of Berzelius.

The number of wood-cuts, representing experimental arrangements, which have been introduced, will give to a beginner a clearer idea of the practical part of each Lecture, and, in our country colleges, may sometimes supply the place of defective or incomplete apparatus. To each Lecture is appended a set of questions. They enable a young student more quickly to apprehend the doctrines which are before him.

JOHN WILLIAM DRAPER.

University of New York,
July 6, 1846.

PREFACE TO THE NEW EDITION.

THE favor with which this book has been received by the public, so many editions of it having been called for, has led me to give it a thorough revision, with a view of bringing it to the present condition of the science.

The reader will find that extensive changes have been made in those parts which treat of the imponderable principles, several of the Lectures having been entirely rewritten.

I hope that the alterations and additions now presented will secure for the work a continuance of that patronage which it has hitherto so extensively received.

JOHN W. DRAPER.

University of New York,
July 20, 1853

CONTENTS.

INTRODUCTION.

CONSTITUTION AND GENERAL PROPERTIES OF MATTER.

LECTURE I.

CONSTITUTION OF MATTER.—*Distinction between Chemistry and Natural Philosophy.—General Division of Chemistry.—Active Forces and Ponderable Bodies.—Proof of the Atomic Constitution of Matter in the Cases of a Solid and a Gas.—Atoms are inconceivably small—They are not in contact—They are unchangeable and indestructible.*

THE physical sciences are divided into two classes, comprehended respectively under the titles of NATURAL PHILOSOPHY and CHEMISTRY.

Natural Philosophy investigates the relations of masses to one another. The movements of tides in the sea under the conjoint influence of the sun and moon; the descent of falling bodies to the earth; the pressure of the atmosphere; the various modes of rendering mechanical forces available, by the action of levers, pulleys, wedges, screws; the phenomena of the planetary bodies, which move in elliptic orbits around a central mass: these are all objects for the consideration of Natural Philosophy.

Chemistry considers the relations of particles to each other; it investigates the properties and qualities of different kinds of matter, their mutual influence, and the action of the imponderable principles upon them. It treats of the causes of those invisible movements which the molecules of bodies around us unceasingly undergo. It also includes many of the phenomena of living beings, explains the objects of respiration, digestion, and other such animal functions.

Every change taking place in bodies is due to the operation of some active force. It is one of the first principles in philosophy, that no movement or mutation can occur in

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Into what classes are the physical sciences divided? Of what phenomena does natural philosophy treat? What are the objects of chemistry?

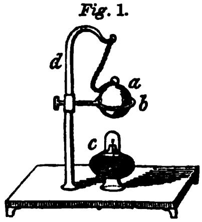
any thing spontaneously; we must always refer it to a disturbing cause. Under the influence of heat, bodies increase in size; under that of electricity, some are dissevered into their component elements; under that of light, vegetables form from inorganic materials their organized structures. The science of chemistry resolves itself, therefore, into two divisions: the first, embracing the consideration of the active forces of chemistry; the second, the objects on which those forces operate.

These active forces are Heat, Light, and Electricity. By the older chemists they are designated as imponderable substances, from the circumstance that they do not affect the most sensitive balances.

We can form no idea of the properties of bodies disengaged from the influence of these principles. Thus we find all material substances existing under one of three conditions, solid, or liquid, or gaseous; and the majority can assume either of these conditions under the influence of heat. Water, for instance, at low temperatures, exists in the solid state as ice; at higher temperatures, it assumes the liquid condition; and at still higher, exhibits the gaseous form. We see, therefore, that it is the degree of heat to which it is exposed which determines its physical state.

One of the first problems which the chemist has to solve is that of determining the true constitution of matter; not of matter in the abstract, but as placed under the influence of these external powers.

Fig. 1.



All the phenomena of chemistry prove that material substances consist of indivisible and exceedingly minute portions, called Atoms, which are placed at certain distances from one another, those distances being variable, and determined by the agency of active forces.

Thus, if we take a copper ball, *a*, *Fig.* 1, an inch in diameter, and provide a ring, *b*, of such a size that the ball at common temperatures can readily pass through it, and having suspended the ball by means of a chain to a stand, *d*, expose

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What are the two leading divisions of chemistry? What are the active forces of chemistry? Why are these called imponderable bodies? What are the three forms of substances? What is it that determines these forms? What is the constitution of matter? **Describe the arrangement of the instrument, *Fig.* 1, and its use.**

it to the flame of a spirit lamp, *c*, as it becomes warm it will be found to dilate, so that, in the course of a few minutes, it can no longer pass readily through the ring, but if placed thereon, remains supported.

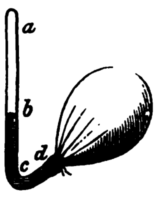
While, under these circumstances, no visible change has taken place in the general properties of the ball, its weight remaining the same as before, its aspect is the same. We conclude, therefore, that its volume has increased *because* we have raised its temperature.

But now, the lamp being removed, the ball, still resting on its ring, begins to cool. In the course of a few minutes it spontaneously drops through the ring. It has, therefore, become less than it was while hot, and, in point of fact, when its original temperature is reached, it has recovered its original size.

From this simple but beautiful experiment, very important conclusions may be drawn. The copper ball, in cooling, becomes less: a fact which at once suggests the idea that its constituent particles have approached each other. In its warm and dilated state, although it exhibited no appearance of transparency, or of interstitial spaces, or pores through which light might pass, its particles were not touching one another, for had they been in actual contact they could not have more closely approached one another, and contraction could not have taken place.

As all bodies contract during the act of cooling, we infer that the particles of which they are composed are separated from each other by intervening spaces, and experiments such as that we have been considering suggest two important observations: 1st. That all material substances are made up of small particles which do not touch each other; and, 2d. That the intervening spaces may be varied at the pleasure of the experimenter.

Fig. 2.



Let us consider a second illustration which will lead us to the same conclusion, selecting as the object of our experiment atmospheric air, a substance differing in all its physical and chemical relations from the copper ball. Let us take a tube of glass half an inch in diameter, and bent

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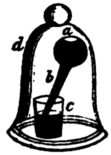
Why, in this experiment, does the ball finally drop through the ring? Could contraction take place if its particles were already in contact? What two conclusions do these facts suggest?

in the form exhibited in *Fig.* 2, *a*, *c*, *d*. The tube is closed at its upper end, *a*; it is bent at *c*, and over its open extremity, at *d*, a bag of India rubber is tied, air tight. In the tube there has been previously inclosed a sufficient quantity of water to fill all the portion *b*, *c*, *d*, but the space from *a* to *b* is occupied by atmospheric air. It is to the volume of this atmospheric air that our attention is directed.

If we compress the India rubber bag in our hand, the volume of the air instantly becomes less, the diminution being greater in proportion as the pressure is greater. Now it is inconceivable that this phenomenon should ensue unless the aerial particles approached each other; but such an approach would be impossible if they were already in contact. Two particles could not occupy the same space at the same time.

We conclude, therefore, that for atmospheric air, a gaseous body, as well as for copper, a solid, the same law holds good, and that both these forms of matter are constructed upon the same type; that they are made up of particles set at distances from one another, and that we can change those distances at pleasure by resorting to changes of temperature or to mechanical forces.

Fig. 3.



It is worthy of observation, that by proper means these interstitial spaces may be greatly increased or diminished, and in very many instances without any striking apparent change occurring in the substance under experiment. Thus, if we take a globe of glass two or three inches in diameter, *a*, *Fig.* 3, with a neck or tube, *b*, proceeding from it, and fill the globe full of water, with the exception of a small bubble of air which occupies its upper part, while the open extremity of the tube, *b*, dips beneath some water contained in a glass jar, *c*, then, covering the whole with an air-pump receiver, *d*, proceed to exhaust, we shall find that the little bubble, *a*, dilates as the machine is worked, and may be rendered a hundred-fold greater than at first. In this expanded condition, its particles must have greatly receded from each other, and yet no remarkable physical change is to be observed. There

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Describe the instrument represented in *Fig.* 2. What is the use of this instrument? With an increase of pressure, what happens to the included air? Can two particles occupy the same space at the same time? What, then, is the deduction from this experiment? What is the experiment given in *Fig.* 3 intended to illustrate?

are no dark or vacuous spaces; but in this attenuated condition, it possesses the aspect which it had when at the common density.

With these preliminary facts, we may now direct our attention, 1st, to the properties of atoms; and, 2d, to the interstitial spaces which part them from each other.

That the atoms of which bodies are composed are exceedingly small, we possess abundant proof. By dissolving substances in liquid media, and then greatly diluting the solution, we can effect a subdivision to an incredible extent. A single drop of a solution of sulphate of indigo will communicate a blue color to one thousand cubic inches of water, so that every drop of that diluted solution contains a portion of the coloring matter. In the same manner, by resorting to proper tests, we can show that a grain of copper, or silver, or gold, may be divided into many millions of smaller parts, each of which may be readily recognized. Nor is it alone by these chemical processes that such a minute subdivision may be effected: by the mechanical process of beating with a hammer, gold may be extended into leaves which are less than the $\frac{1}{200000}$ part of an inch thick, a dimension far less than the human eye, unassisted by microscopes, can discover, for the smallest spherical object visible to it is about $\frac{1}{2000}$ part of an inch in diameter. By other processes, it has been estimated that this metal may be divided to such an extent, that a single grain will yield 80 millions of millions of visible parts. The world of organization furnishes us with still more striking proofs. There exist animalcules of which it would require many millions to make up the bulk of a common grain of sand, yet these are furnished with digestive and respiratory organs, with circulating juices, and with contrivances as elaborate as the mechanism of the highest orders of life. How minute, then, must the constituent particles be!

All the results of chemistry prove that the ultimate atoms of bodies are unchangeable and imperishable. We can not effect their destruction, or impress them with new or unusual qualities, any more than we can call them into existence. Those familiar instances in which it appears that material

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To what extent can the constituent atoms be removed? To what extent can sulphate of indigo be divided? Can similar results be obtained from metalline bodies? What evidence have we on this point from mechanical processes? What argument may be drawn from the construction of animalcules? Are the atoms of bodies either changeable or perishable?

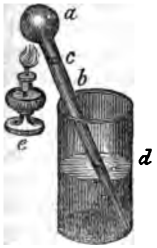
substances are destroyed or dissipated, when properly understood, are only cases of transformation, or of the origin of new compounds. An atom once created can by no process be destroyed. When, therefore, coal disappears in the act of burning, it is not, in reality, a destruction of the particles of which the coal consists, but these particles, uniting with one of the constituents of the air, give origin to a body of a different form, an invisible and elastic substance, from which, however, the carbonaceous particles could be reobtained by resorting to proper methods. It is, moreover, obvious that the continuance and stability of the universe itself depend on the fact that by no natural process can material atoms be either created or destroyed.

LECTURE II.

Constitution of Matter.—*Of the Interstices between Atoms.—They are not casual, but regulated.—Two Forces are required to produce this Result.—Cohesion and Heat.—Proof that these Forces act through very limited Spaces.—Analogy between the Structure of Matter and the Structure of the Universe.*

Having, in the preceding lecture, established the atomic constitution of matter, let us now direct our attention to the intervening interstices.

Fig. 4.



The distances that part the atoms of a given mass from one another are not casual or determined at random; their magnitude is perfectly regulated. Thus, if we take a glass bulb, *a*, *Fig*. 4, with an open neck, *b*, and having filled the neck with water to a given mark, *c*, immerse its open extremity in a glass of water, *d*, it will be found that, so long as no extraneous cause intervenes, the water remains perfectly stationary at its original point, *c*; but if, by the application of a spirit lamp, *e*, we raise the temperature of the

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How can the apparent destruction of bodies be explained? Are the spaces between atoms regulated or at random? What is the experiment, *Fig.* 4, designed to establish?

air included in the bulb, it promptly dilates; a dilatation which, however, does not proceed with irregularity, for the volume of the air steadily increases as the heat is steadily continued. Let the lamp now be removed, and as the temperature descends, the water comes back again to its original point, because the air recovers its original bulk.

In the same manner, if we repeat the experiment illustrated in *Fig.* 3, we shall see that the bubble of air does not expand with irregularity as the pump is worked. It does not at one moment suddenly dilate, and then remain motionless, but for each movement of the pump it increases correspondingly; and as soon as the pressure is restored to the interior of the machine, it shrinks back to its original size. But these expansions and contractions are the result of movements among the constituent atoms, which at one time recede farther apart, and at another come closer together. It follows, therefore, from these considerations, that the distances which separate the constituent atoms are not determined by chance or at random, but their magnitude is strictly regulated.

To produce these results two forces are required: 1st, a force of attraction, which continually tends to draw the atoms closer together; 2d, a force of repulsion, which tends to remove them farther apart. The distance at which they are placed, at any particular moment, is determined by the balancing of these forces; if the attractive force is made to increase in intensity, the particles approach; if the repulsive, they recede.

Names have been given to these forces, the attractive force being known under the name of cohesion; caloric or heat appears to be the principle of repulsion.

All attractive and repulsive forces diminish as the distances through which they act increase. The attractive force of the earth, the force of gravitation, is of a certain intensity on the surface of our planet, but it diminishes as the distances become greater. The forces which connect together the bodies of the solar system, and, indeed, one planetary system with another, act through great intervals of space; thus the attractive force of the sun, operating through

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Can the same theory be proved by resorting to other disturbing processes? How many forces are required to account for these facts? What is their nature? What is the relation between heat and repulsion? Through what spaces can these forces operate?

many millions of miles, retains the earth in her orbit. But the attractive and repulsive forces which determine the position of the constituent atoms of bodies are limited to a very minute space. If we take two leaden bullets, and having pared a small portion from the surface of each, so as to expose a brilliant metallic spot, bring them within an inch of one another, they exert no perceptible attraction, and may be drawn apart with the utmost facility; we may diminish the distance between them to the tenth, the hundredth, the thousandth part of an inch, and still the same observation may be made; we may even bring them in apparent contact, and the attractive influence of the particles of the one upon those of the other is still undiscoverable; but, on pressing them together, we can finally bring them within the range of each other's influence, and then they cohere together as though they were a single mass, and require a considerable effort to separate them.

Fig. 5.

The apparatus figured in the margin serves to illustrate the same result. Suspend a circular piece of plate glass, *a*, *Fig.* 5, an inch in diameter, to one of the arms of a balance, *b*, *c*, counterpoising it on the opposite arm by weights placed in the scale-pan, *d*. Beneath the plate of glass place a cup, *e*, containing some quicksilver, and it can be proved that so long as the glass is at a sensible distance from the surface of the quicksilver, no attraction between them is exhibited; for, were such the case, the arm of the balance should incline, and the glass descend. As long as the smallest perceptible space intervenes, no attractive action is developed; but on bringing the two surfaces in contact, they cohere; and now it requires the addition of a considerable weight in the scale-pan to draw them asunder. This result does not depend on the pressure of the air, for it equally takes place in a vacuum.

From experiments of this kind, therefore, we gather that the spaces through which molecular attractions and repulsions can act are very limited, and it follows of necessity that the interstices which separate the atoms of bodies are

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How can this be proved by leaden bullets? Describe the apparatus, *Fig.* 5. What is its use? What the fact which is proved by it? Does the experiment depend on the pressure of the air?

exceedingly minute, for through those spaces the action of these forces extends. If the limiting distance through which molecular attraction and repulsion can reach is, as there is reason to believe, from some of the experiments of Newton, less than the millionth of an inch, we are entitled to conclude that the interstitial spaces are much smaller.

To what, then, do these results finally point in regard to the constitution of matter, if, as we have seen, the constituent atoms themselves are inconceivably minute, and the spaces that separate them as small as we have reason to conclude? We may look upon the universe as representing on a grand scale the constitution of matter on a minute one. The planetary bodies which compose the solar system, and which are held in their orbits by the attraction of a central mass, are separated from one another by enormous spaces, to which their own magnitudes bear but an insignificant proportion. About forty such bodies, great and small, compose the group or family to which our earth belongs. But as there are systems of opaque planetary bodies, so also there are systems of self-luminous suns, which compose together colonies of stars. In the universe myriads of such systems exist, separated from one another by spaces so great that the mind can form no just idea of them. A planet, such as Jupiter with its attendant satellites; a self-luminous star, like our sun with its surrounding bodies; a group of shining stars, such as are scattered over our skies; a collection of such groups as form the nebular masses; these, in succession, furnish us with a series of illustrations on a scale continually increasing in dimensions of the constitution of matter, which is made up of isolated atoms placed at variable distances from each other, the size of these atoms bearing an insignificant proportion to the spaces intervening between them.

The human mind is so constituted that it is unable to appreciate whatever is exceedingly great or exceedingly small. We can neither attach a precise idea to the magnitudes and grander relations of the universe, nor to the atomic constitution of a grain of dust. Hereafter, when we come to speak of the phenomena of light, we shall see that by following the same philosophical methods which have been

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What are the limiting distances through which molecular forces can act? State the analogy between the constitution of the universe and the constitution of matter.

cultivated with such success in astronomy, and which have furnished us with a general view of the constitution of the universe, we also can obtain a general view of the scale which has been used in the constitution of material bodies, a scale which brings before us new ideas of time and space. When we are told that in the millionth part of a second a wave of violet light pulsates or trembles seven hundred and twenty-seven millions of times, and that, if we divide a single inch into ten millions of equal parts, this violet wave is only one hundred and sixty-seven of such parts in length, we obtain a glimpse of the scale on which material bodies are composed, and must confess the inability of the human imagination to form a proper conception of such results, though we may feel a just pride in the intellectual power which has ascertained them.

PART I.

THE FORCES OF CHEMISTRY.

LECTURE III.

Heat.—*Preliminary Ideas of the Nature of Heat.—Influence of Heat in the inorganic and organic Worlds.—Modes of Transference.—Illustrations of Expansion.—Heat determines the Magnitude and Form of Bodies—Affects our Measures of Time and Space—Determines the Distribution of Animals and Plants.*

Writers on chemistry signify by the term Caloric the agent which excites in our bodies the sensation of heat. By some, however, heat and caloric are used synonymously. Those who look upon this force as if it were a material and imponderable substance, ascribe to the particles of caloric a self-repulsive power, and an attraction for the particles of ponderable bodies.

So great is the control which caloric exercises over all kinds of chemical changes, that few experiments can be made in which transformations of substances take place without contemporaneous disturbances of temperature. In some, heat is evolved; in others, cold is produced. To this agent, moreover, we so constantly resort for the promotion of molecular changes, that the chemist has been not inaptly designated the Philosopher by Fire.

It is not alone in the inorganic world that the influences of caloric are traced. Life can not take place except within certain limits of temperature; limits which are comprehended between the freezing and the boiling points of water, that is, within one hundred and eighty degrees of our thermometer; and, in point of fact, within a narrower range than that. It is, therefore, not alone in chemistry, but also

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What is caloric? What is heat? On the hypothesis that caloric is an imponderable substance, what are its properties? Why is it that the study of caloric is of such great importance in chemistry? Within what limits of temperature can living things exist?

in physiology, that the relations of this agent are of interest.

When an ignited mass, as a red-hot ball, is placed in the middle of a room, common observation satisfies us that it rapidly loses its heat, its temperature descending until it becomes the same as that of surrounding walls and other bodies. This loss is due to several causes. A part of the heat is carried away by contact with the body which supports the ball, a part by certain motions established in the surrounding air, and a part by radiation. This removal passes under the name of *transference;* and as soon as the temperature has declined to that of the adjacent bodies, an *equilibrium* is said to have been attained.

There are two methods by which caloric can be transferred: 1st. By radiation; 2d. By convection. Of the former we have two varieties—general radiation, and interstitial radiation.

Fig. 6.

Under the influence of an increasing temperature substances expand. This takes place, whatever their form may be, whether solid, liquid, or gaseous. The experiment which is illustrated by *Fig.* 1 establishes this fact in the case of a copper ball; and that the same law holds good for liquids, may be proved by taking a glass tube, *a, b, Fig.* 6, open at the extremity, *a,* but having a bulb, *c,* blown upon it at the other end. The bulb and a part of the tube, as high as *b,* is to be filled with any liquid substance, such as water, spirits of wine, or oil; and the heat of a lamp, *d,* applied. As the liquid becomes warm, it dilates, as is shown by its rising in the tube, the dilatation increasing with the temperature.

Fig 7.

If now the liquid be removed from the bulb, and the tube be inverted, as shown in *Fig.* 7, in a glass of water, we can prove the same fact for gaseous substances, taking, as the type or representative of them, atmospheric air; for, on simply grasping the bulb, *c,* in the hand, the air which is in it dilates with the warmth, and bubbles pass in succession from the open end of the tube through the water in the glass, *d.*

Through what causes does the temperature of a body descend? What is meant by transference and by equilibrium? In how many ways can caloric be transferred? How many varieties of radiation are there? By what means can it be proved that solids, liquids, and gases expand as their temperature rises, and contract as it descends?

We conclude, therefore, that solids, liquids, and gases expand as their temperature rises, and contract as their temperature falls.

The magnitude of all objects around us is determined by their temperatures. A measure which is a yard long in summer is less than a yard in winter; a vessel which holds a gallon in winter will hold more than a gallon in summer. And as the degrees of heat vary not alone at different seasons of the year, but also during every hour of the day, it is clear that the dimensions of all objects must be undergoing continual changes. The appearance of stationary magnitudes which such objects present is therefore altogether a deception.

Heat thus determines the size of bodies; it also determines their form. As we have said, there are three forms of bodies, solid, liquid, and gaseous. A mass of ice, if exposed to a temperature of above 32°, melts into water; and if that water be raised to 212°, it passes into the form of steam—a gaseous body. The assumption of the solid, the liquid, or the gaseous condition, depends on the existing temperature.

In the same manner that it affects our measures of space, caloric affects our measures of time. Clocks and watches measure time by the vibrations of pendulums, or the oscillations of balance wheels, the uniformity of the action of which depends on the uniformity of their size. When the temperature rises, the rod of a pendulum lengthens, and its vibrations are made more slowly; the clock to which it is attached loses time. When the temperature declines, the pendulum shortens; it beats too quick, and the clock gains. Similar observations may be made in the case of watches. To obviate these difficulties many contrivances have been invented, such as the gridiron pendulum, the compensation balance wheel, &c. Advantage has also been taken of such substances as expand but little for a given elevation of temperature; and thus excellent clocks have been made, the pendulum rods of which were formed of a slip of marble.

The natural, as well as the artificial measures of time, depend on the influence of heat. Our unit of time—the

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Is there any variation at different seasons n the length of measures or the capacity of vessels? What is it that determines *the form* of bodies? How can caloric affect our measures of time? By what contrivances have this difficulty been avoided?

day—is the period which elapses during one complete rotation of the earth on her axis. The length of this period is determined by the mean temperature of her mass. Should the mean temperature of the whole earth fall, her magnitude must become less, or, what is the same thing, her diameter must shorten. It results from very simple mechanical principles, that a given mass, the dimensions of which are variable, rotating on its axis, will complete each rotation in a shorter space of time as its diameter becomes smaller. Thus, when we tie a weight to the end of a thread, and, swinging it round in the air, permit the thread to wrap round one of the fingers, as the thread shortens by wrapping, the weight accomplishes its revolution in a less period. Now, transferring this illustration to the case before us, if the mean temperature of the earth had ever declined, she must have become less in size, and, therefore, turned round quicker, and the length of the day must have necessarily been less. But astronomical observations, for a period of more than 2000 years back, prove conclusively that the length of the day has not changed by so small a quantity as the $\frac{1}{100}$ part of a second, and we therefore are warranted in inferring that the mean temperature of the globe has not perceptibly fallen.

The distribution of heat on the surface of the earth determines, for the most part, the distribution of animals and plants; to each climate its proper denizens are assigned. It is this which confines the lion to the torrid regions, and the white bear to the frigid zone. In the case of man, who has the power of accommodating his diet and his dress to external requirements, almost any part of the earth is habitable. Plants, like the inferior animals, have their localities determined chiefly by the influence of heat. It is for this reason that even in tropical climates, if we ascend from the foot to the top of a very high mountain, we successively pass through zones occupied by trees and plants which, differing strikingly from one another, have analogies with those which occupy respectively the torrid, the temperate, and the frigid zones, on the general surface of the earth.

Do these disturbances affect the natural as well as the artificial measures of time? How can it be proved that the mean temperature of the earth has not for many centuries changed? What is it that chiefly determines the distribution of plants and animals?

LECTURE IV.

EXPANSION OF GASES AND LIQUIDS.—*Rudberg's Law.—Regularity of Gaseous Expansion.—Ascentional Power of expanded Gas.—Amount of Air contained in the same Volume at different Temperatures.—Gas Thermometers.—Expansion of Liquids.—The Mercury Thermometer.*

IF we compare together the three forms of bodies, as respects their changes of volume under the influence of heat, we shall find that for a given rise of temperature, gases expand the most, liquids intermediately, and solids least of all. To this rule but few exceptions are known; liquid carbonic acid, however, expands about four times as much as any gaseous body.

When heated from the freezing to the boiling point of water,

1000	cubic inches	of iron	become	. . . . .	1004
1000	"	" water	"	. . . . .	1045
1000	"	" air	"	. . . . .	1365

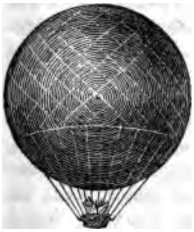
Recent experiments have proved that gases differ among themselves in expansibility, though the differences are not to any great extent. For the permanently elastic gases, atmospheric air may be taken as the type; the experiments of Rudberg show that it expands $\frac{1}{493}$ of its volume at 32° for every degree of Fahrenheit's thermometer. As the same quantity of gas occupies very different volumes at different temperatures, it is necessary, in this and other such cases, to state some specific temperature at which the estimate of its volume is made; the same gaseous mass occupies a much greater space at 75° than it does at 32°. In the instance before us, we consider the original volume to be that which the gas would have at 32°, and, as has been said, every degree above that point will increase the volume by $\frac{1}{493}$ of the bulk it then possessed.

Gases expand with uniformity as their temperature in-

Of solids, liquids, and gases, which expand most by heat? In what respect is liquid carbonic acid peculiar? Is there any difference among gases in their rates of expansion? What is Rudberg's estimate of the amount of expansion of air? Why are we required in these cases to adopt a specific temperature? Do gases expand uniformly?

creases. Ten degrees of heat produce the same relative effect, whether applied at a low or at a high temperature; this regularity probably arises from the want of cohesion which the gaseous particles exhibit; as we shall presently see, it is not observed in the case of liquids and solids.

Fig. 8.



The change in specific gravity of atmospheric air, when it is warmed, is one of the causes of the rise of Montgolfier balloons. These, which were invented in France in the year 1782, consist of a bag or globe of light materials, such as paper or silk, with an aperture at the lower part, through which, by the aid of combustible material, as straw or shavings, the air in the interior may be rarefied. On a small scale, they may be made of thin tissue paper, pasted together so as to form a sphere of two or three feet in diameter, an aperture being cut in the lower portion six inches or more in width, and beneath it a piece of sponge, soaked in spirits of wine, suspended. This being set on fire, the flame rarefies the air in the interior of the balloon, which, though it might be at first flaccid, soon dilates, and the whole apparatus will now rise in the air, precisely on the same principle that a cork rises from the bottom of a vessel of water.

There is, however, another cause in operation in this case. The combustible material commonly employed gives rise during its burning to the disengagement of the vapor of water—steam, which is much lighter than air. In the operation of cupping, the glass receives for a moment the flame of a spirit lamp, and is then quickly applied to the surface of the skin; the vapor of water quickly condensing, and the heated air contracting, a very good vacuum can be made.

From the circumstance that the volume of air changes so readily with changes of temperature, contracting under the influence of cold, and dilating under that of heat, it is plain that in different climates on the earth's surface a very different amount of atmospheric air is included under the same measure. A vessel which will hold precisely one ounce weight at the mean temperature of New York, will hold more than an ounce in the cold polar regions, and less than

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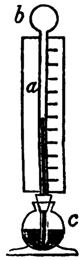
What are Montgolfier balloons, and why do they rise? Why is it that the weight of air in a given measure is different at different places?

an ounce in the tropics. In the former situation the air is more dense, because it is in a contracted condition by reason of the low temperature, and therefore a greater weight is included under a given volume; in the latter, the reverse is the case. These facts are supposed to be connected with certain physiological results, as we shall hereafter see.

The expansions of atmospheric air taking place with regularity as the temperature rises, that substance is occasionally employed as a means of thermometric admeasurement. The air thermometer, called also Sanctorio's thermometer, but which was invented by Galileo about 1603, consists of a tube of glass, *a*, *Fig.* 9, terminated at its upper extremity by a bulb, *b*; the other end of the tube being open, dips beneath the surface of some colored water in a cup or reservoir, *c*, which serves also as a foot or support to the instrument. The bulb and part of the tube are full of air; the remainder of the tube is occupied by the colored water, which, by its movements up and down, serves to indicate changes in the volume of the included air. To the side of the tube a scale of divisions is affixed, and the tube is not arranged so tightly in the neck of the reservoir but that there is a free passage for the air in and out of that part of the instrument. On touching the ball with the fingers, the air within it becomes warm, dilates, and depresses the liquid in the tube, or, on touching it with any cold body, it contracts, and the liquid rises.

Fig. 9.



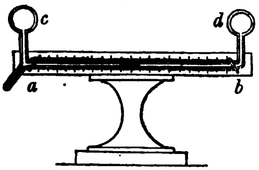
This form of thermometer is liable to a difficulty which renders it impossible to rely upon its indications, except under particular circumstances. It is affected by variations of atmospheric pressure as well as by changes of heat. To prove that this is the case, place such a thermometer under the receiver of an air pump, as shown in *Fig.* 10; on producing the slightest degree of rarefaction, the liquid in the tube is instantly depressed, and on restoring the pressure of the air, it returns to its original position.

Fig. 10.

Describe the thermometer of Sanctorio. By whom was it really invented? How can the use of this instrument be illustrated? By what disturbing cause is Sanctorio's thermometer affected? How may that be proved?

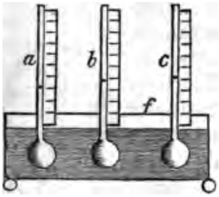
The differential thermometer is a gas thermometer, so arranged as to be free from the foregoing difficulty. It consists of a glass tube, *a b*, *Fig.* 11, bent into the form represented in the figure, with a bulb blown on each extremity. To the horizontal part a scale of divisions is affixed. The bulbs are full of atmospheric air, and in the tube there is a small column of colored liquid, which serves by its movements as an index. To understand the action of this instrument, it is only necessary to consider what will take place when it is carried into a room the temperature of which is very high or very low. If the former, the air in both bulbs, becoming equally warm, will expand in both equally, and the column of fluid which acts as an index being pressed equally in opposite directions, does not move at all. If the latter, the air in both bulbs cooling equally, contracts equally, and again no movement ensues. It is immaterial, therefore, whether we warm or cool both bulbs, the instrument is motionless. But if one of the bulbs, *c*, is made warmer than the other, *d*, movement at once ensues in the liquid column from *c* toward *d*. Movement of the index, therefore, takes place when the bulbs are at different temperatures, and hence the instrument is called a differential thermometer. It was formerly of considerable use in researches connected with radiant heat.

Fig. 11.



Different liquids expand differently for the same thermometric disturbance. This is easily shown by an apparatus, as *Fig.* 12, in which we have three tubes, *a*, *b*, *c*, with bulbs on their ends, dipping into a trough, *f*, of tin plate. The tubes and bulbs should be all of the same size, and filled with the liquids to be tried to the same height. To each a scale is annexed. Let *a* be filled with quicksilver, *b* with water, and *c* with alcohol; on pouring hot water into the trough, two phenomena are witnessed:

Fig. 12.



Describe the differential thermometer. If this instrument be carried into a warm and then into a cold room, does its index move? Why is it called differential thermometer? How can it be shown that different liquids expand differently?

1st. All the liquids expand; 2d. They expand unequally when compared together, the mercury expanding least, the water intermediately, and the alcohol most.

On being heated from the freezing to the boiling point of water,

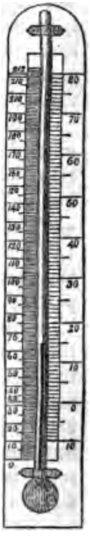
Alcohol	expands	1 part in	9
Oil	"	1 "	12
Water	"	1 "	22·76
Mercury	"	1 "	55·50

Liquids which have arisen from the condensation of such gases as cyanogen, sulphurous acid, and especially carbonic acid, are among the most expansible bodies known. Thus liquid carbonic acid, warmed from 32° to 86°, expands four times as much as atmospheric air.

In the case of several groups of liquids, as alcohol, sulphuret of carbon, and wood spirit, it has been found that the rate of expansion is precisely the same if estimated at equal distances from their several boiling points.

Unlike gases, all liquids expand irregularly as their temperature rises, a given amount of heat producing a much greater effect at a high than at a low temperature. Ten degrees of heat, applied to a given liquid at 200°, will produce a greater expansion than if applied at 100°. The reason appears to be, that as a liquid dilates its cohesive force becomes less, because its particles are being removed farther from each other; and, as the cohesive force weakens, its antagonistic power, the heat, produces a greater effect.

Fig. 13.



Advantage is taken of the properties of liquids in the making of thermometers. For these purposes, alcohol and mercury are the fluids selected. The mercurial thermometer consists of a fine capillary tube, *Fig.* 13, with a bulb blown on one end; the bulb and part of the tube are to be filled with quicksilver, and the air expelled from the rest of the tube by warming the bulb until the metal rises by expansion to the top of the tube, and at that moment hermetically sealing the glass by

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Of mercury, water, and alcohol, what is the order of expansion? Do liquids, like gases, expand with regularity? What is the cause of the difference? For making thermometers, what liquids are selected? How is the mercurial thermometer made?

melting the end of it with a blow-pipe. As the thermometer cools, the quicksilver retreats from the top of the tube, and leaves a vacuum above it.

It remains now to annex such a scale to the instrument as may make its indications comparable with other instruments. To effect this, the thermometer is plunged into a vessel containing melting ice or snow, and opposite the point at which the quicksilver stands is marked 32°. It is then transferred to another vessel in which water is rapidly boiling, and the point opposite which it then stands is marked 212°. The intervening space is divided into 180 equal parts; these are degrees, and similar divisions are made on the scale for all points above 212° and below 32°. The zero point, or cipher of the scale, is therefore 32 degrees below the freezing point of water.

It has been observed, that in the course of time the freezing point of some thermometers changes. This is due to the pressure of the air acting on the bulb, the thin glass of which yields to a certain extent, and the liquid consequently rises in the tube. The same effect will often take place instantaneously by exposing a thermometer to a high temperature. It is therefore necessary to verify from time to time the graduations of these instruments.

The zero point of the thermometric scale is not to be regarded as indicating the total absence of heat. Observations have been made in cold climates of degrees almost 80° below 0; and by the aid of liquefied protoxide of nitrogen, —220° has been reached.

The melting of ice and the boiling of water are the fixed thermometric points. They have been selected for the purpose of rendering thermometers comparable with each other. The numbers which are attached to these points are arbitrary, and accordingly three different scales have been introduced in different countries. That which is commonly used in America and England is the Fahrenheit scale, which, as we have just seen, makes the melting point of ice 32°, and the boiling of water 212°. In France, the Centigrade scale is employed; this has for the melting of ice 0°, and for the boiling of water 100°. In some parts of Europe,

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Is there a vacuum above the mercury in the tube? How is the scale adjusted? What is the freezing and what the boiling point? What is meant by the zero? What are the fixed points? Why are these fixed points employed? What three scales have been introduced? What is the Centigrade scale?

Reaumur's scale is used, the points of which are respectively 0° and 80°. Chemical authors always specify the thermometer they use by a letter attached to the numbers; thus, 212 F., 100 C., 80 R., refer to the boiling of water on Fahrenheit's, the Centigrade, and Reaumur's scales. It is obvious that these degrees are readily convertible into each other by a simple arithmetical process.

LECTURE V.

Expansion of Liquids and Solids.—*Importance of the Thermometer.—Alcohol Thermometer.—Point of Maximum Density of Liquids.—Maximum Density of Water connected with Duration of the Seasons.—Expansion of Solids.*

From the considerations advanced in Lecture III., we can perceive the importance of the thermometer. As all our measures of space and time are affected by variations of temperature, the thermometer, which measures those variations, must necessarily be one of the fundamental instruments of physical science. If we state that a given object is a foot long, we must specify the temperature at which the measure was taken, for at a lower temperature it will be less than a foot, and at a higher it will be more.

There are several peculiarities which quicksilver possesses that eminently fit it to be a thermometric fluid. 1st. It can always be obtained in a state of uniform purity. 2d. It expands with greater regularity than most liquids, as its temperature rises, and when included in a bulb of glass, as in the common instrument, the irregularity of expansion of the glass almost exactly compensates the irregular expansion of the quicksilver, and hence the true temperature is very accurately marked. 3d. The range of temperature between the points of solidification and boiling is great, the former being —39° Fahrenheit, and the latter at 662° Fahrenheit; that is, about seven hundred degrees. 4th. It does not soil or moisten the tube in which it is contained, nor

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What is Reaumur's? Can these be converted into each other? Why is the thermometer such an important instrument? What are the qualities which quicksilver possesses which fit it for these uses?

does it adhere thereto, but moves up and down with facility. 5th. It is affected much more readily than water or spirits of wine by a given amount of heat, as we shall see when we come to speak of the capacity of bodies for caloric.

When very low temperatures have to be measured, such as approach or are below the freezing point of quicksilver, we resort to thermometers filled with alcohol, tinged with some coloring matter to make its movements visible. This fluid requires a diminution of temperature of more than 180° below the zero of our scale before it solidifies, and hence is adapted to the measurement of low temperatures.

If we take some water at 100° Fahrenheit, and, placing it in a vessel in which we can observe its volume, reduce its temperature, we shall find, agreeably to the general law heretofore given, that as it cools it contracts. As it successively passes through 80 60, 50 degrees, it exhibits a continuous diminution; but as soon as it has fallen below 39°, although it may still be cooling, it begins to expand, and continues to do so until it reaches 32°, when it freezes. If we take some water at 32° and warm it, instead of expanding, it contracts, until it reaches 39°; but from that point, any farther elevation of temperature causes it to obey the general law, and it expands.

It is obvious, therefore, that if we take water at 39°, it is immaterial whether we warm it or cool it, it will expand. At that temperature, therefore, this liquid occupies the smallest bulk, and is at its greatest density, for neither by cooling nor warming can we reduce it to smaller dimensions. The particular thermometric point at which this takes place is designated "*the point of maximum density of water*," and very exact experiments show that it is about 39½° Fahrenheit.

There are many liquids which thus have points of maximum density, and which expand previous to assuming the solid form. In the act of solidifying, water undergoes a very great dilatation, amounting to about $\frac{1}{9}$th of its volume; this is the reason that ice floats upon it. Several melted metals exhibit the same phenomenon, and advantage is taken of

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Under what circumstances are alcohol thermometers used? Does water contract regularly when cooled from 100° to 32°? Does it regularly expand when warmed from 32°? At what thermometric point does the change take place? What is the designation given to that point? Why is that designation appropriate? Are there other liquids which have points of maximum density?

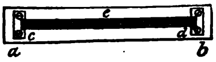
the fact in the arts. The alloy of which printers' types are formed, or stereotype plates cast, in the act of solidifying, expands, and hence forces itself into every part of a mould in which it may be poured, and copies it perfectly; the same is the case with melted cast iron. But it is impossible to obtain good castings with such a metal as lead, which contracts as it cools, and therefore tends to separate from the surface of the mould, or to leave vacant spaces in it.

The fact that water possesses a point of maximum density is connected, to a great extent, with several remarkable natural phenomena; the freezing of water on its surface is one of these results. If the water contracted as it cooled, the colder portions would descend, and rivers or ponds would commence to freeze at the bottom first, the solidification advancing steadily upward. Such collections of this liquid would, during the course of a winter, become solid masses of ice, and they would greatly prolong that season of the year, from the length of time required to thaw them. But with things as they at present exist, the coldest water is the lightest; it floats on the warm water below; solidification takes place on the surface, and a veil or screen is soon formed which protects the liquid beneath. When the warm weather of spring comes on, the ice on the surface is in the most favorable position for melting, and thus the point of maximum density of water comes to be connected with the duration of the seasons.

If salt is added to water, the point of maximum density descends, until, when the quantity is sufficiently great, it sinks below the freezing point. The observations just made apply therefore only to fresh, and not to salt water.

We have already proved by the instrument represented in *Fig.* 1, that solid substances dilate as their temperature rises. The same results may be made very apparent by the apparatus, *Fig.* 14. Upon a strong basis or wooden board, *a*, *b*, let there be fastened two brass uprights, *c d*, with notches cut in them, so as to receive the ends of the metallic bar, *e*. This bar should be very slightly shorter than the distance between the two up-

Fig. 14.



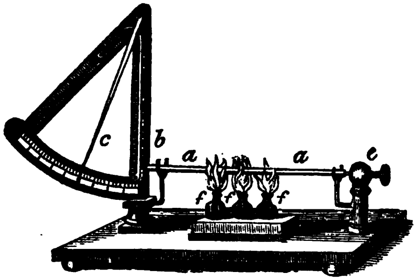
What advantage is taken of this fact in the arts? Why does water freeze first on its surface? How is it that these facts are connected with the duration of the seasons? How does the instrument, *Fig.* 14, prove that a metallic bar expands when heated?

rights, that when it is placed resting in their grooves, if we take hold of it and move it, it will make a rattling sound as we push it backward and forward. If now we pour hot water upon the bar, it dilates, as is proved on restoring it to its position between the uprights; it will no longer rattle, for it occupies the whole distance between them, and perhaps there may even be a difficulty in forcing it into the grooves.

For the determination of very small spaces, the sense of hearing may often be far more effectually employed than the sense of sight.

The pyrometer, of which we have several varieties, is represented in *Fig.* 15. It may serve to illustrate the fact that solid substances expand by heat. It consists essentially of a metallic bar, *a a*, resting at one end against an immovable prop, *e*, the other end bearing upon a lever, *b*. The extremity of this lever presses upon a second lever, *c*, which also serves as an index. Upon the index-lever a spring acts so as to oppose the lever *b*, and the point of the index ranges over a graduated scale.

Fig. 15.



If now lamps be applied to the bar, it expands, and the pressure taking effect on the lever, puts it in motion, the index traversing over the scale. On removing the lamp the bar contracts, and the spring, pressing the lever in the opposite direction as soon as the bar is cold, brings the index back to its original point.

Describe the pyrometer and the mode of using it.

LECTURE VI.

EXPANSION OF SOLIDS.—*Contraction of Solids.—They expand irregularly.—Different Solids expand differently.—Points of Maximum Density.—Metallic Thermometers.—Nature of Thermometric Indications.*

It is a popular error, that when solid bodies have been heated, they do not return, on cooling, to their original size. Without resorting to any experimental proof, a few simple considerations will satisfy us on this point. If a bar of metal be exposed for a length of time in the open air, it will of course be subjected to continual changes of temperature; whenever the sun shines on it it will expand, and during the cold night it will contract. If now, on cooling, it did not rigorously come back to its original size, but remained a little elongated, we should observe it increasing from day to day, and no matter how minute the difference might be, in the course of time it would become perceptible. Public edifices in cities are often surrounded by railings of cast iron, which are constantly exposed for years to variations of heat and cold, but did any person ever observe them to grow or increase in size? We conclude, therefore, that solid bodies, on cooling to their original temperature, regain their original bulk.

By linear dilatation we mean increase in one dimension, as in length; by cubic dilatation, increase in all dimensions, length, breadth, and thickness. Knowing the amount of linear dilatation of a given solid, we can easily ascertain its cubic dilatation, by multiplying the former by 3. This result is near enough for practical purposes.

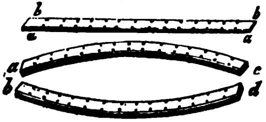
Solids expand increasingly as their temperature rises, a phenomenon already observed in the case of liquids, and due to the same cause—a diminution of the cohesive force of the particles, because of their increased distance.

Compared with one another, different solid substances expand differently for the same disturbance of temperature.

What decisive proof can be given that solids, on cooling to their original temperature, come back to their original size? What is linear dilatation? What is cubic dilatation? How can the former be converted into the latter? Does the same solid expand uniformly or increasingly as its temperature rises?

This may be shown by having bars of different metals, but of precisely the same lengths, adjusted to the grooves of the instrument, *Fig*. 14. If a bar of brass and one of iron be compared, it will be found that the brass expands more than the iron, for it will entirely fill the distance between the uprights, while the iron rattles between them.

Fig. 16.



This difference of expansion is also shown when two long slips of metal are soldered together face to face. If we fasten in this manner a slip of brass to a similar slip of iron, as in *Fig*. 16, in which *a a* is the slip of iron and *b b* the slip of brass, at common temperatures the compound bar is adjusted so as to be straight, but if hot water be poured upon it, it immediately curves, as represented at *a c*, the strip of brass being on the outside of the curve; if, on the other hand, it be artificially cooled, the curvature is in the other direction, as at *b d*, the iron being on the outside of the curve. All this is obviously due to the fact that, for the same disturbance of temperature, the brass contracts and dilates much more than the iron. When the temperature is raised, the brass becomes the longer, and compels the compound bar to curve, it occupying the greater length of the curve. When the temperature falls, the brass becomes the shorter, and the bar curves in the opposite direction.

By taking advantage of these metallic combinations, pendulums and balance-wheels for the accurate measurement of time have been constructed. The gridiron pendulum and the compensation balance are examples.

The following table exhibits the expansion of various solid substances when heated from the freezing to the boiling point of water:

Zinc (cast) . . .	1 in 323	Gold	1 in 682
Lead	1 " 351	Iron (wire) . .	1 " 812
Tin	1 " 516	Palladium . . .	1 " 1000
Silver	1 " 524	Platinum . . .	1 " 1167
Copper	1 " 581	Flint glass . .	1 " 1248
Brass	1 " 584	Black marble . .	1 " 2883

Ice is much more expansible than the metals, surpassing,

Do different solids expand alike? Of brass and iron, which expands most? Describe the construction of a compound bar, and the effect of warming and cooling it. What instruments are constructed on this property?

in this respect zinc. Glass and platinum can be cemented together without parting as they cool, for their rates of expansion are nearly alike. The process of cutting glass by means of a hot rod depends on unequal expansion.

Though a solid substance is usually regarded as expanding equally in any direction, this is not always the case. In crystals, of which all the sides and angles are not alike, there may be a very different rate of expansion in different directions, and it has even been observed that they may contract in one direction while they are expanding in another. The figure of a crystal of carbonate of lime is for these reasons different at the freezing and the boiling point of water.

There are some metallic bodies which exhibit points of maximum density in the solid state. Rose's fusible metal is an example. When heated from 32° to 111°, it expands, but after that point it contracts, and continues to do so until it reaches 156°, at which temperature it is actually less than it is at 32°. From this point it again expands, and continues to do so until it melts, which takes place at about 201° Fahrenheit.

Liquid thermometers have a limited range of indication. They can not be exposed to degrees of heat approaching the point of solidification, for then their movements become irregular; neither can they be used for degrees near their boiling point, for if vapor should form, the instrument would be destroyed. But as there are many metals which require a very great degree of heat to melt them, it might be expected that we should find among this class bodies well suited for thermometric purposes. The instrument given in *Fig.* 15 serves to illustrate such an apparatus, and also the difficulties encountered in its use. From the small extent to which metals expand, this form of instrument requires levers, or wheels, or some multiplying machinery connected with it, to make the changes more perceptible; but such mechanical contrivances can not be employed without the introduction of certain causes of disturbance. Friction occurs on the centres of motion, the teeth of the wheels play on each other, and therefore the index, instead of moving with regularity and precision as the expanding bar presses moves by starts often of several degrees at a time, then it

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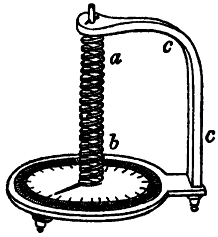
What are the properties exhibited by Rose's fusible metal? Why can not liquid thermometers be used for very low and very high temperatures? What difficulties occur in the use of this instrument?

pauses, and once more starts again, the whole movement being incompatible with exactness.

A compound strip of metal, as represented in *Fig.* 16, is free from many of these difficulties, and if of sufficient length, it will indicate temperatures with great delicacy. A modification of this instrument is known under the name of Breguet's thermometer. It consists of a very slender strip of platinum, soldered to a similar piece of silver, and curved into a helix, or spiral, *a b*, *Fig.* 17. It is fastened at its upper extremity to a metallic support, *c c*, and from its lower portion an index projects, which plays over a graduated circle. The expansion of silver is more than twice as great as that of platina; when, therefore, the temperature of the thin spiral rises, curvature, with a corresponding motion of the index, takes place; and if the temperature falls, there is a movement in the opposite direction, as has been already explained. This Breguet's thermometer is one of the most delicate instruments we have, for the mass of the spiral is so small compared with the mass of mercury in an ordinary thermometer, that every change in the surrounding temperature is followed with rapidity and precision.

Fig. 17.



For many purposes in science and the arts, it is necessary to determine temperatures above a red heat. Daniell's pyrometer is intended to meet these occasions. It consists of an arrangement by which the expansion of a bar of iron or platinum, while exposed to the heat to be measured, is registered. The amount so registered is subsequently determined upon a divided scale, and the temperature estimated therefrom. By the aid of such an instrument very high temperatures may be determined, and thus it has been shown that brass melts at 1869° Fahrenheit, copper at 1996°, gold at 2200°, and cast iron at 2786°.

The thermometer is commonly regarded as a measurer of heat. A little consideration will satisfy us that it is only so in a limited sense; it does not indicate the quantity of

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Describe Breguet's thermometer. Why is this instrument so sensitive? Describe the principle of Daniell's pyrometer. Give the melting points of some of the most important metals. Does the thermometer measure the heat to which it is exposed?

heat present in the bodies to which it is exposed, for if immersed in a glass of water and a bucket of water drawn from the same well, it stands at the same point; but of course there are very different quantities of caloric in the two cases. It is not, therefore, the quantity of heat, but the intensity, which it measures; that is to say, not the quantity abstractly, but the quantity contained in a given space; and in the mercury thermometer, that space is measured by the volume of the mercury in the instrument itself. It does not tell how much heat is absolutely present in the substances to which it is exposed; and though it may stand at the same height in the same quantity of two different liquids, it does not follow that those liquids contain the same amount of caloric, as we are immediately to see.

LECTURE VII.

CAPACITY OF BODIES FOR HEAT.—*Methods of determining Capacities.—Warming.—Melting.—Cooling.—Mixture.—Comparison between the Thermometer and Calorimeter.—Definition of Specific Heat.*

MANY years ago it was discovered by Boyle, that if two bottles of the same size and form were filled with different liquids, and placed before the fire so as to receive its heat equally, their temperature did not rise similarly; thus, if one bottle was filled with water and the other with quicksilver, the temperature of the latter would rise much more rapidly than that of the former; and, on making the experiment with a little care, it will be found that the same quantity of heat will raise the temperature of mercury twice as high as that of an equal volume of water.

By extending these experiments to other substances, it has been fully proved *that different bodies require different amounts of heat to warm them equally.*

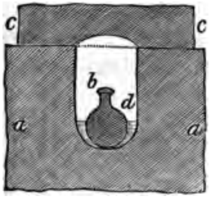
What is it then, that it does actually measure? What is meant by the intensity of heat? Describe Boyle's experiment with water and quicksilver. To what general result do such experiments lead? State the different methods by which capacities for heat may be determined.

Calorimetry.

There are several different methods by which the capacity of bodies for heat may be determined, such as, 1st, by warming; 2d, by melting; 3d, by cooling; 4th, by mixture.

The first of these methods has already been illustrated by the experiment of Boyle. It consists essentially in exposing the same weight of the substances to be tried to a uniform source of heat, as, for example, a bath of hot water, and examining how high their temperature has risen in a given space of time. Thus it will be found that it takes thirty times as long to warm water as to warm mercury, when equal weights are used, and hence we infer that the capacity of water for heat is thirty times that of quicksilver.

Fig. 18.



The second process is involved in the action of the calorimeter, the operation of which may be easily understood from *Fig.* 18. Take a solid block of ice, *a a*, in which a cavity of the form represented at *b* has been made, and provide a slab of ice, *c c*, which may close completely the mouth of the cavity. Suppose it were required to determine the relative capacities of water and quicksilver for heat. In a glass flask, *d*, place one ounce of water, and by immersing the flask in a bath of hot water, raise its temperature up to a given point, as, for example, 200°; then place the flask at this temperature in the cavity *b*, and put on the cover, *c c*. The hot water in the flask begins to cool, and in descending to 32°, the point to which it will eventually come, a certain portion of the surrounding ice is melted, the water resulting therefrom collects in the bottom of the cavity, and when the cooling is complete, it may be poured out and measured.

In the next place, put in the flask one ounce of quicksilver, the temperature of which is raised as before to 200° by immersion in the hot-water bath; deposit the flask in the ice cavity, and put on the cover. As the quicksilver cools, the ice melts, and when the collected water is measured, it is found to be less than in the other case, in the

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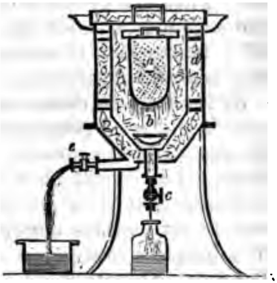
Give an illustration of the first process. Show how the capacities of water and mercury may be ascertained by the second. What are the relative capacities of equal weights of these bodies?

proportion of 1 to 30. A given weight of water will therefore melt 30 times as much ice as an equal weight of quicksilver, in cooling through the same number of degrees.

Fig. 19.



The calorimeter of Lavoisier, which is represented in *Fig.* 19, acts on the same principle as the block of ice. It consists of a set of tin vessels within each other; in the central one, *a*, the substance to be examined is placed, and between this and the next vessel, at *b*, the ice to be melted is introduced, broken into small fragments; the water arising from the melting flowing off through a stop-cock, *c*, at the bottom into a measuring glass; and in order to avoid any portion of the ice being melted by the warm external air, another layer of fragments of ice is placed on the outside at *d*, and the water arising from it is carried off by a lateral stopcock, *e*.

The third process, the method by cooling, known also as the method of Dulong and Petit, consists essentially in ascertaining the length of time required to cool through a given number of degrees. A substance which, like water, has a great capacity for caloric, and therefore contains a large amount of it, requires a greater length of time to cool; but one like quicksilver, the capacity of which is small, having less heat to give forth, requires a corresponding short space of time. The method by cooling requires several precautions; among others, the bodies under investigation should be placed in vacuo. It gives very exact results.

The method by mixture may be readily understood. If a pint of water at 50° be mixed with a pint of water at 100°, the temperature will be 75°, that is the mean. But if a pint of mercury at 100° be mixed with a pint of water at 40°, the temperature of the mixture will be 60°: so that the forty degrees lost by the mercury can only raise the temperature of the water twenty degrees. It appears, therefore, that when equal *volumes* of these fluids are examined, the capacity of the water for heat is about twice as great

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Describe the calorimeter of Lavoisier. Describe the method of Dulong and Petit. Describe the method by mixture.

as that of mercury, and of course the result becomes still more striking when equal *weights* are used, being then, as we have seen, in the proportion of 1 to 30.

The method of mixtures is not limited to the investigation of liquid substances, but it may also be extended to solids. Thus, if a pound of copper, heated to 300°, be plunged into a pound of water at 50°, the resulting temperature is 72°; from which it appears that the capacity of water for heat is about ten times as great as that of copper.

By resorting to these various methods, the capacities of a great number of substances have been determined, and in the treatises on chemistry, tables exhibiting such results are given. But it will have been noticed, from the foregoing instances, that it is not the absolute quantities of heat in bodies that we thus determine, but only relative quantities in substances compared together. Such tables require, therefore, one substance to be selected with which all the others may be compared, and for solids and liquids water has been chosen. Its capacity for heat is represented by 1·000, and with it they are compared. For gaseous bodies atmospheric air is chosen.

Capacity of Bodies for Heat.

Water	1000	Cobalt	106·96
Ice	513	Zinc	95·55
Charcoal	414	Copper	95·15
Sulphur	241	Arsenic	81·40
Glass	203	Silver	57·01
Diamond	147	Gold	32·44
Iron	113·79	Platinum	32·43
Nickel	108·63	Mercury	33·32

From this it appears that the capacity of ice for heat is nearly half that of water, which stands at the head of all solid and liquid substances. In the form of steam the capacity of water is less than in the liquid form, in the ratio of 847 to 1000 for equal weights. The calorific capacity of a substance therefore changes with its physical condition.

The method which has been resorted to for determining the capacity of gases, is to pass them, when heated carefully to 212°, through a spiral tube immersed in water, the temperature of which is measured. Owing to experimental dif-

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Is this limited to liquid substances? Do we thus determine the absolute quantities of heat in bodies? What substance is used to compare solids and liquids? What is the substance for gases?

ficulties, the results arrived at by different chemists exhibit considerable variation.

By contrasting the nature of the results given by the calorimeter, *Fig.* 19, with the indications of a thermometer, we shall see more clearly what it is that the latter instrument in reality points out. The calorimeter measures quantities of heat, the thermometer intensities. As has been said, a thermometer placed in two vessels of different capacities, filled with water from the same source, will stand at the same height in both, and indicate the same temperature. But it needs no experiment to assure us that, if these different quantities of water were placed successively in the interior of the calorimeter, they would melt different quantities of ice, the one melting more of the ice in proportion to its greater weight compared with the other.

Dr. Black, who was one of the early investigators of these phenomena, introduced the term "Capacity of Bodies for Heat," implying the idea that this principle, entering their pores, could be taken up by different bodies in different amounts. Thus, if we have two pieces of sponge of the same size, one of which is of a very dense, and the other of a porous texture, and cause them to imbibe as much water as they can hold, the porous sponge will of course contain the greater quantity. These sponges may therefore be said to have different "capacities for water;" and this is precisely the idea which is conveyed in Black's doctrine of capacity.

But, upon these principles, it would follow that the lighter a body is, that is, the greater the interstices between its atoms, the more caloric it should be able to contain. Oil, therefore, which will float upon water, ought to have a greater capacity for heat than water; but, in fact, it is the reverse, for its capacity, instead of being greater, is not one half. To avoid these difficulties, the term specific heat has been introduced by most writers, and the term capacity abandoned, a change which I think is to be regretted, especially when it is recollected that this objection does not contemplate the difference of the weight of atoms.

The specific heat of bodies, or their capacity for caloric, increases with their temperature. Upon Black's doctrine,

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How do the indications of the calorimeter compare with those of the thermometer? On what analogy is Black's doctrine of "capacity" founded? What is the objection to this doctrine? What is meant by specific heat? Does the capacity of bodies change with their temperature?

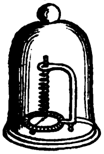
the cause of this is readily understood, for, in simple language, the pores become larger, and there is therefore room for more heat. Solid substances, when violently compressed, evolve a portion of their caloric: thus, a piece of soft iron, when hammered, becomes red hot. The doctrine of Black here again offers a ready explanation, for on the same principle that a sponge, when compressed, allows a certain portion of its water to exude, so the metalline mass, when its particles are forced together, allows some of its caloric to escape.

LECTURE VIII.

Capacity for Heat and Latent Heat.—*Variability of Capacities under Compression and Dilatation.—Theory of the Formation of Clouds.—The Fire Syringe.—Cold in the upper Regions of the Air.—Connection between Specific Heats and Atomic Weights.—Latent Heat.—Caloric of Fluidity.*

When the volume of a gas increases, its capacity for heat increases, and a diminution of volume is attended with a diminution of capacity. Thus, if we place a Breguet's thermometer under the receiver of an air pump, and exhaust rapidly, a sudden reduction of temperature is indicated, arising from the fact that, as the rarefaction is effected, the capacity increases, an increase which is satisfied at the expense of a portion of the sensible heat.

Fig. 20.



Upon the same principle we can explain the sudden appearance of a fog or cloud, when moist air is quickly rarefied. It will be seen, when we speak of the nature of vapors, that the quantity of vapor which can exist in a given space depends on the temperature; thus, if a space saturated with vapor is cooled, a portion of the vapor assumes the liquid form. When, therefore, by the aid of an air-pump, we suddenly rarefy air saturated with moisture under

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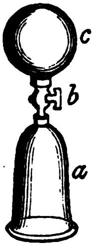
Does the capacity of bodies change under compression? How is this explained agreeably to Black's doctrine? When the volume of a gas changes, what are the changes in its specific heat? What is the fact which the experiment of *Fig.* 20 proves? What is the theory of the production of clouds?

a receiver, the capacity increases, cold is produced, and a part of the water takes on the form of drops. It is on this principle that the nephelescope acts : it consists of a receiver, *a*, *Fig.* 21, connected with a flask, *c*, by an intervening stop-cock, *b*; the stop-cock being closed, the receiver is exhausted by the pump, and now, on suddenly opening the stop-cock, so that the air contained in the flask may rapidly expand into the receiver, a mist or cloud makes its appearance, due to the deposit of water in the form of minute drops. If the air at the time be very dry, it may be purposely rendered moist by being exposed to water.

Fig. 21.



When atmospheric air is suddenly compressed, its capacity for heat diminishes; this is well shown by an instrument such as is represented in *Fig.* 22, consisting of a syringe, with a piston moving perfectly air tight in it. On the end of the piston there is an excavation, in which a piece of tinder may be fastened; the piston being rapidly forced into the syringe, the air is compressed, the capacity for heat becomes less, caloric is evolved, and the tinder set on fire. At one time these syringes were used as a means of obtaining fire.

Fig. 22.

The variation in capacity of substances under variation of volume may be clearly understood and readily borne in mind by Black's doctrine, as illustrated in the case of a moistened sponge. If a sponge which has imbibed as much water as it can hold be compressed, a portion of the water exudes, just as the air in the syringe allows a portion of its heat to escape when pressure is made. On relaxing the force on the sponge, and allowing it to dilate, it will take up an increased quantity of water; and air, when suddenly dilated, as we have seen, has its capacity for heat increased.

From these facts, it appears that the heat of bodies exists under two different forms, as sensible and insensible heat. In the experiment with the syringe, just related, the heat that sets fire to the tinder existed previously to compression in the air; it existed as insensible heat, but during the compression it put on the form of sensible heat. The same tran-

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Describe the nephelescope. What is the result of the action of this instrument? When air is compressed, why does it emit heat? How can these changes be accounted for by Black's doctrine? What are the relations between sensible and insensible heat?

sition is also recognised in the action of the nephelescope the heat, which was sensible before rarefaction, becomes insensible, and cold, or a depression of temperature is the result

The great degree of cold which reigns in the upper regions of the atmosphere is due, to a considerable extent, to the capacity of that dilated air for heat. On the same principle we can explain the formation of clouds from transparent atmospheric air: a stratum of air, reposing on the surface of the sea, or the moist earth, becomes saturated with vapor; by the warmth of the sun or other causes, it begins to rise in the atmosphere, and as it rises it expands, because the pressure upon it is continually becoming less. An increased capacity is the result of its dilatation, and, as is the case in the nephelescope, cold is produced, and a deposit of a part of the moisture takes place; this moisture, appearing under the form of minute drops, is what we call a cloud.

From the small capacity of quicksilver for heat, we see one of the reasons that it is a suitable substance for forming thermometers; it warms rapidly and cools rapidly, and therefore follows variations of temperature much more promptly than water and most other liquids.

There is a connection between the specific heat of several simple bodies and their atomic weights, pointing out the fact that elementary atoms have in many instances the same specific heat; recently the same conclusion has been established in the case of certain oxides, carbonates, and sulphates.

Table of the Specific Heats of Elementary Atoms.

Iron	3·0928	Sulphur	3·2657
Zinc	3·0872	Mercury	3·7128
Copper	3·0172	Silver	6·1742
Lead	3·2581	Arsenic	6·1326
Tin	3·3121	Antimony	6·5615
Nickel	3·2176	Gold	6·4623
Cobalt	3·1628	Iodine	6·8462
Platinum	3·2054	Bismuth	2·1917

From this table it appears that the first ten substances show a close approximation in their capacities for heat, if the quantities used be in proportion to the *atomic* weights instead of *equal* weights; that the next five have a double capacity; and the last a capacity less by about one third.

Describe the mode in which clouds form. Why does the capacity of quicksilver fit it for a thermometric liquid? What is the relation of the specific heat of many elementary bodies?

LATENT HEAT.

First Change of Form. Heat of Fluidity.

When solid substances, which can resist a due temperature without decomposition, are exposed to an increasing heat, a point is eventually reached at which they assume the liquid state. This point, known as the point of fusion or melting point, may be regarded as fixed for each substance. For mercury it is 39° below the zero of the thermometer; for iron, about 2800° above.

Table of the Melting Points of Bodies.

Iron	2800	Sulphur	232
Gold	2016	Wax	142
Silver	1873	Phosphorus	108
Zinc	773	Tallow	92
Lead	612	Olive Oil	36
Tin	442	Ice	32
Potassium	135	Mercury	—39

Some substances, perhaps all to a greater or less extent, pass through a condition intervening between the solid and liquid state, assuming a pasty consistency. The manufacture of glass depends on such a property; it is also strikingly shown by various oils and wax. Indeed, different liquids may be said to present different degrees of liquidity: this is well seen when sulphuric acid, a dense, sluggishly-moving body, is compared with sulphuric ether, a substance of remarkable mobility. The liquidity of the liquid state seems generally to be increased by elevation of temperature.

If we take a mass of ice, the temperature of which is at the zero point, and bring it into a warm room, examining the circumstances under which its temperature rises, they will be found as follows: the mass of ice, like any other solid body, warms with regularity until it reaches 32°; then, for a considerable period of time, no farther elevation is perceptible, but it undergoes a molecular change, assuming the liquid condition; when this is complete, the temperature again commences to rise.

That we may have precise views of these facts, let us suppose that the mass of ice and the warm room into which it is carried have such relations to each other that the temperature of the former can rise from the zero point one degree per minute; for thirty-two minutes the temperature of the

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Describe the change which ice undergoes when warming.

ice will be found to increase, and at the end of that time, a thermometer, if applied, would stand at 32°. But now, although the heat is still entering the ice at the rate of a degree per minute, the process of warming ceases, and for 140 minutes no farther rise takes place; the ice now commences to melt, and in 140 minutes the liquefaction is complete. The temperature then again rises, and continues to do so with regularity.

We infer from results like the foregoing, that about 140 degrees of heat are absorbed by ice in passing into the condition of water; and as this heat is not discoverable by the thermometer, it is designated as latent heat.

A similar fact appears when any liquid, such as water, passes into the gaseous or vaporous condition. Thus, if some water be exposed to a fire which can raise its temperature at the rate of one degree per minute, that effect will continue until 212° are reached; at that point, no matter how much the heat be increased, the temperature remains stationary. The water undergoes a change of form, assuming the condition of a vapor, and the change is completed in about 1000 minutes. In this, as in the former instance, we infer that a large amount of heat has become latent, or undiscoverable by the thermometer, and that it is occupied in establishing the elastic form which the water has assumed.

The caloric which thus disappears when a solid assumes the liquid form, takes also the designation of caloric of fluidity, and that which disappears in the formation of a vapor, the caloric of elasticity.

Table of the Caloric of Fluidity of Bodies.

Water	142°	Zinc	493°
Sulphur	145°	Tin	500°
Lead	162°	Bismuth	550°
Beeswax	175°		

By the method of mixtures the same results may be established; thus, if a pound of water at 32° is mixed with a pound at 172°, the mixture will have the mean temperature, that is, 102°; but if a pound of ice at 32° be mixed

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Is there any pause in the elevation of its temperature? How many degrees of heat are absorbed during the liquefaction of ice? What is latent heat? How many degrees of heat are absorbed during the vaporization of water? What is the latent heat of steam? What is caloric of fluidity? What is caloric of elasticity? How can the doctrine of latent heat be established by the method of mixtures?

with a pound of water at 172°, the mixture still remains at 32°, and the reason is clear, from the foregoing considerations, that ice, in passing into the liquid state, requires 140° of caloric of fluidity which are rendered latent.

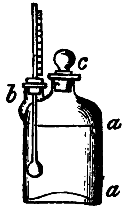
LECTURE IX.

LATENT HEAT.—*Heat evolved in Solidification.—Theory of freezing Mixtures.—Expansion during Solidification.—Fixity of the Melting Point.—Latent Heat connected with the Duration of the Seasons.—Nature of Vapors.—Caloric of Elasticity.*

WHEN a liquid assumes the solid form, a considerable amount of heat is evolved. The cause is readily understood, from what we have seen taking place during the reverse process ; which has led us to the fact that the difference between any given solid and the liquid which arises from it by melting is in the large amount of latent heat which is found in the latter, and which is occupied in giving it its form.

A saturated solution of sulphate of soda may be cooled from its boiling point to common temperatures, in a vessel tightly corked, without solidification taking place ; but when the cork is withdrawn crystallization ensues, and heat is evolved. This may be proved by taking a bottle, *a a*, *Fig.* 23, filled with such a solution ; and having introduced the bulb of an air thermometer through the neck, *b*, by means of an air-tight cork, the mouth, *c*, of the bottle is to be carefully stopped. When the whole apparatus has reached the ordinary temperature of the air, the stopper at *c* is withdrawn, and solidification at once takes place, or, if it should at first fail, the introduction of a crystal of sulphate of soda will bring it on. At that moment it will be perceived that not only does the thermometer indicate a rise of temperature, but if the bottle be grasped, it will be found to be sensibly warm.

Fig. 23.



Is heat absorbed or evolved when a liquid solidifies? What is the cause of this? How can it be illustrated with a solution of sulphate of soda?

With care, water may be cooled to a point far below tha of freezing without assuming the solid form. If, under thes unusual circumstances, it be agitated, solidification of a part of the water ensues, and heat is evolved, the temperature rising to 32°.

On these principles depends the action of freezing mixtures, of which the following is an example: If we take eight parts of crystallized sulphate of soda, and mix it in a thin tumbler with five parts of hydrochloric acid, the sulphate of soda, from being a solid, assumes the liquid form; and taking, in order to effect that change of form, caloric from surrounding bodies, it reduces their temperature. This may be shown by placing four parts of water in a thin glass test tube, and stirring it about in the mixture; the water speedily freezes, even though the experiment may be made on a warm summer day.

Table of Freezing Mixtures.

Mixtures.	Pts.	Thermometer Sinks.	Deg. of Cold.
Nitrate of Ammonia . Water.	1 1	from +50° to +4°	46°
Sulphate of Soda . . Hydrochloric Acid .	8 5	from +50° to 0	50°
Snow or pounded Ice Common Salt . . .	2 1	to 5°	*
Snow . . . . Diluted Nitric Acid .	3 2	from 0° to —46°	46°

All these mixtures depend essentially on the principle under consideration—that latent heat must be furnished to a substance passing from the solid to the liquid state. They consist of various solid substances, the liquefaction of which is brought about by the action of other bodies: thus, in the instance we have seen, the sulphate of soda is brought from the solid to the liquid state by hydrochloric acid, in which it dissolves, and heat is necessarily absorbed.

Many substances, when solidifying, expand. This is the case with water, in which the amount of expansion is about $\frac{1}{9}$th of the bulk. The force which is exerted under these circumstances is very great, and capable of tearing open the strongest vessels. On a small scale, this may be easily

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Can water be cooled below 32° without freezing? Give an example of a freezing mixture. What are the principles on which freezing mixtures act? What is the amount of the expansion of water in the act of freezing?

shown by filling a bottle full of water, and, having introduced the cork, fastening it tightly down with a piece of wire. On putting such a bottle into a freezing mixture, for example, snow moistened with nitric acid, congelation promptly takes place, and the bottle is burst.

All processes of freezing are therefore processes of warming, for the heat which has given the liquid form reappears when solidification takes place.

The freezing point of water is usually spoken of as a fixed point, and is marked as such upon the scales of our thermometers; but if water be cooled without allowing any movement or agitation of its parts, it may be brought as low as 15°. It is then in the same condition as the saturated solution of sulphate of soda just alluded to. The slightest motion is sufficient to solidify it. But, though water will retain its liquid form far below its freezing point, ice can not be brought above 32° without melting. The melting of ice, and not the freezing of water, is therefore the fixed thermometric point.

We have seen that the possession of a point of maximum density by water exerts a great effect upon the duration of the seasons; a similar observation might be made as respects its latent heat. If ice, by the absorption of a single degree of heat, when it passes from 32°, could turn into water, the great deposits of winter would suddenly melt, and inundations be frequent; or, if water, by losing a single degree of heat, turned into ice, freezing would go on with great rapidity. To the melting of ice, or the freezing of water, time is necessary; the 140° of latent heat have to be disposed of; this, therefore, serves to procrastinate the approach of winter, and causes the spring to come forward with more measured steps. In autumn the water has 140° degrees of heat to give out to surrounding bodies before it solidifies; in spring it must receive the same amount before it will melt. This, therefore, serves as a check upon sudden changes in the seasons.

Second Change of Form—Heat of Elasticity.

Having thus discussed the leading facts observed in the

How may the force with which this expansion takes place be illustrated? Is the freezing point of water a fixed thermometric point? How low can water be cooled without freezing? Is the melting of ice, or the freezing of water, the fixed thermometric point? What connection has the latent heat of water with the duration of the seasons?

change from the solid to the liquid condition, let us now turn our attention to the second change of form, the passage from the liquid to the gaseous state.

Exposed to a rise of temperature, liquid substances boil at a particular point, which varies with their nature, as the following table shows.

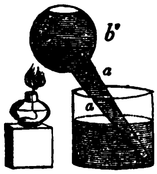
Table of Boiling Points.

Ether	96°	Nitric Acid	248°
Sulphuret of Carbon	118°	Oil of Turpentine	314°
Ammonia	140°	Phosphorus	554°
Alcohol	173°	Sulphuric Acid	620°
Water	212°	Mercury	662°

A technical distinction is made between a gas and a vapor; by the latter we understand a gas which will readily take on the liquid form.

Some of the leading peculiarities in the constitution of vapors may be exhibited by the following experiment: Take a glass tube, *a a*, *Fig.* 24, with a bulb, *b*, blown on its upper extremity; pour water into the bulb, filling the tube to within an inch or two of the end; this vacant space fill with sulphuric ether; and now, closing the end of the tube with the finger, invert it in a glass of water, as is represented in the figure. The ether, being much lighter than water, at once rises to the upper part of the bulb, as is shown by the light space, the bulb being of course full of ether and water conjointly.

Fig. 24.



On the application of a spirit lamp the ether vaporizes, and presses the water out of the bulb into the glass cup. Three important facts may now be established.

1st. Vapors occupy more space than the liquids from which they arise.

2d. They have not a misty or fog-like appearance, but are perfectly transparent.

3d. When their temperature is reduced, they collapse to the liquid state.

That the first of these observations is true, is at once seen on comparing the quantity of ether with the volume of va-

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What is the distinction between a gas and a vapor? Describe the experiment represented in *Fig.* 24. What is the difference between a vapor and the liquid which forms it, as to volume? Have vapors necessarily a cloudy appearance?

por which has risen from it; the ether occupying but a small space at the top of the bulb, the vapor fills it entirely. We perceive, moreover, that ethereal vapor does not possess that cloudy appearance which is popularly attached to the term vapor, but that it is as transparent as atmospheric air. And, on removing the lamp, so that the temperature may fall, the liquid rushes up violently into the bulb, exhibiting the ready collapse of the ether vapor into the condition of a liquid.

We have already proved that a large amount of heat becomes latent, constituting the caloric of elasticity of vapors. The temperature of steam is 212°, as is that of the water from which it rises; but it contains about 1000° of latent heat, which gives to it its new form. Different vapors possess different quantities of latent heat; thus, for ether, the number is 163°; for alcohol, 376°; and, as we have said, for water, 1000°; or, according to the recent exact experiments of Brix, 972°. It is this great quantity of caloric which constitutes steam so efficient an agent for warming. The steam arising from one gallon of water will raise the temperature of five gallons and a quarter from the freezing to the boiling point; its caloric of elasticity is nearly sufficient, were the steam a solid body, to make it visibly red hot in the daylight. In the warming of buildings by steam pipes, each square foot of their surface will heat 200 cubic feet of surrounding air to 75°, and will require about 170 cubic inches of boiler capacity for its proper supply.

LECTURE X.

VAPORIZATION.—*Vapors form at all Temperatures.—Form instantly in a Void.—Effects of removing Pressure.—Measure of Elastic Force of Vapors.—Cumulative Pressure.—Failure of Marriotte's Law.—Elasticity increases with Temperature.—Maximum Density of Vapors.*

VAPORIZATION goes on at all temperatures. It is not necessary that the boiling point should be reached; even ice

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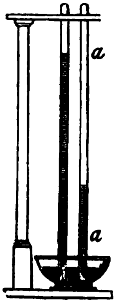
On reduction of the temperature, what phenomena do they exhibit? How are these three facts proved? What is the amount of caloric of elasticity of steam? Mention it also in the case of ether and alcohol.

will evaporate away. The thin films of this substance often seen incrusting windows may disappear without undergoing the intermediate process of fusion, and a mass of ice, freely exposed to the air on a dry, frosty day, loses weight. Steam, therefore, rises from water at all temperatures, but with more rapidity and a higher elastic force as the temperature is higher.

Fig. 25.



In a vacuum vapors form instantaneously. If we take a barometer, *a a*, *Fig.* 25, and pass into the Torricellian vacuum which exists at its upper part a small quantity of sulphuric ether, even before it has reached the void space, vapor forms, and the mercury is instantly depressed. Under ordinary circumstances, when the instrument is standing at 30 inches, the column at once falls to 15 or 16, the space being now filled with the vapor of ether; and if in succession other liquids are tried, the same general result is obtained—instantaneous vaporization; but the amount of vapor set free is different in the different cases.

Diminution of atmospheric pressure is, therefore, favorable to vaporization, and were the pressure of the air entirely removed, there are many liquids which would assume a permanently aerial form. Take a glass tube, A, *Fig.* 26, closed at one end and open at the other, and, having filled it with water, invert it in a cup, B, and introduce into it a little sulphuric ether, which will rise to *a*, the top of the tube. The apparatus is next to be placed under an air-pump receiver, and exhaustion made: the ether enters into ebullition, and gives off vapor which is quite transparent. As long as the reduction of pressure continues, the ether keeps the gaseous form, but on readmitting the air, it returns to the liquid state. By increase of pressure, as well as by diminution of temperature, vapors may be reduced to the liquid condition.

Fig. 26.

Though the law that vapors occupy more space than the liquids from which they come is of universal application, the increase of volume is by no means the same in all cases.

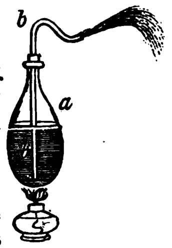
How can it be proved that vaporization goes on at all temperatures? What is the effect which ensues when a vaporizable liquid is passed into a Torricellian vacuum? What substances exist commonly in the liquid state, in consequence of the pressure of the air? What is the effect of an increased pressure on vapors? Do all liquids expand equally in assuming the vaporous state?

Under ordinary circumstances of pressure, a cubic inch of water at its boiling point produces nearly a cubic foot of steam, or 1696 cubic inches more accurately. The same quantity of alcohol produces 519 cubic inches, and of oil of turpentine 192 cubic inches.

The elastic force exerted by vapors under certain limits can be measured by the apparatus given in *Fig.* 25. The theory of the process is very simple. The height at which the barometer stands is determined by the pressure of the air. In the experiment there described, as long as there is nothing to counterbalance that pressure, the mercury is forced up by it in the tube to a height of 30 inches; but on introducing some ether, the vapor which forms, exerting an elastic force in the opposite direction, tends to push the mercury out of the tube. On the one hand, we have the pressure of the air; on the other, the elastic force of the ethereal vapor; they press in opposite directions, and the resulting altitude at which the mercury stands expresses, and, indeed, measures the elastic force of the vapor. Thus, at a temperature of eighty degrees, water will depress the mercurial column about 1 inch, alcohol about 2 inches, and sulphuric ether about 20. These numbers, therefore, represent the elastic force of the vapors evolved.

In close vessels, from which there is no escape, or where the escape is greatly retarded, a constantly accumulated force is generated when the temperature is raised. Thus, if we place some water in a flask, *a*, *Fig.* 27, into which a tube, *b b*, is inserted air-tight by means of a cork, and bent in the form exhibited in the figure, and dipping nearly to the bottom of the flask, on the application of a spirit lamp, the vapor generated, having no passage of escape, accumulates in the upper part of the flask, and, exerting its elastic force, presses the liquid through the tube in a continuous stream. The mechanical force which thus arises, when every avenue of escape is stopped, is strikingly exhibited by the little glass bulbs called candle bombs; these are small globules of glass, about as large as a pea, with a neck an inch long;

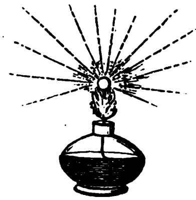
Fig. 27.



How can the elastic force of vapors be measured by the barometer? What is the principle involved? When water is heated in a vessel from which the steam can not escape, what is the effect? How may this be illustrated?

into the interior a drop of water is introduced, and the termination of the neck hermetically sealed by melting the glass. When one of these is stuck in the wick of a candle or lamp, as in *Fig.* 28, the heat vaporizes a portion of the water, and there being no passage through which the steam can escape, the bulb is burst to pieces with a loud explosion; a mechanical force which is wonderful when we consider the amount of water employed. It is a miniature representation of what takes place on the large scale in the bursting of high-pressure steam-boilers.

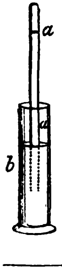
Fig. 28.



MARRIOTTE's law, the law which assigns the volume of a gas under variations of pressure, applies, under certain restrictions, to the case of vapors. A permanently elastic gas, when the pressure is doubled, contracts to one half of its former volume; if the pressure be tripled, to one third, and so on, but not so with vapors; if, upon steam, as it rises from water at 212°, any increase of pressure be exerted, this vapor at once loses its elastic form, and instantly condenses into water. But vapors, like atmospheric air, if the pressure upon them is diminished, follow Marriotte's law; thus, if the pressure be reduced to one half, steam at once doubles its volume. For vapors, therefore, Marriotte's law holds for diminutions of pressure, but in other instances, when the pressures are increased, it apparently fails, the vapors relapsing into the liquid form.

That the elasticity of a vapor increases with its temperature, may be readily proved by taking a tube one third of an inch in diameter and 20 inches long, closed at one end and open at the other, *a a*, *Fig.* 29, with a jar, *b*, an inch or more in diameter and 20 inches deep. Let the tube be filled with quicksilver, so as to leave a space of half an inch, into which ether may be poured; invert the tube in the deep jar, also containing quicksilver; the ether of course rises to the upper closed extremity. If now the tube be lifted in the jar as high as possible without admitting external air, a certain portion of the ether will va-

Fig. 29.



What is Marriotte's law? Does it apply in the case of vapors under a diminution of pressure? Does it apply under an increase? What relation is there between elasticity and temperature?

porize, and, depressing the quicksilver, its elastic force may be measured by the length of the resulting column. If now the end of the tube be grasped in the hand, or if it be slightly warmed by the application of a lamp, the mercurial column is at once depressed, proving that the elastic force of the vapor is increasing. As soon as the tube is warmed to the boiling point of the ether, the column of mercury is depressed exactly to the level on the outside of the tube. At this point, therefore, it balances, or is equal to the pressure of the air.

Now let the tube be depressed in the jar ; it will be seen with what facility the vapor reassumes the liquid condition. As the tube descends, the vapor condenses, and the mercury keeps constantly at the same level.

Under these circumstances, it follows that the vapor is at its maximum density. We can not increase that density by bringing pressure to bear upon it by depressing the tube, for the moment the attempt is made the vapor liquefies.

The point of maximum density rises with the temperature of the vapor. The density of air at 212° being taken at 1000°, that of the vapor of water at its maximum density will be as follows :

Table of the Maximum Density of Water-vapor.

Temperature.	Density.	Weight of 100 Cubic In.
32°	5·690	·136 grains
50°	10·293	·247
60°	14·108	·338
100°	46·500	1·113
150°	170·293	4·076
212°	625·000	14·962

By exerting pressures to a sufficient degree on various gases, they have been converted into liquid bodies. Sulphurous acid, cyanogen, chlorine, carbonic acid, protoxide of nitrogen, have yielded in this way. But hydrogen, oxygen, and nitrogen may be exposed to pressures of 50 atmospheres without liquefying. The condensation of carbonic acid is sometimes conducted on the large scale in strong vessels of wrought iron. If the resulting liquid is allowed to escape into the air, a portion is frozen by the evaporation of the rest,

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How can the increase of elastic force under these circumstances be shown? At the boiling point of a liquid, what is the elastic force of its vapor equal to? What is meant by the maximum density of a vapor? How can it be shown that vapors thus in a Torricellian void are at the maximum density?

and a snowy, solid substance is the result. This, moistened with sulphuric ether, will depress the thermometer to —135°

LECTURE XI.

EBULLITION.—*Theory of Boiling.—In Papin's Digester Water never Boils.—Instantaneous Condensation of Vapors.—Effect of Variations of Pressure.—Effect of Nature of the Vessel.—Boiling on Mountains.—Effect of Red-hot Surfaces.*

BY introducing different liquids into a tube, arranged as that represented in *Fig.* 29, we can prove that the observation holds good in every case, that, as soon as the boiling point of a liquid is reached, the elastic force of the vapor rising from it is equal to the pressure of the air.

We have said that at a temperature of 80°, the vapor of water will depress the mercurial column of a barometer about one inch; but if the temperature be raised to 212°, the mercury is at once depressed to the level in the cistern; at that temperature, therefore, the elastic force of the vapor is equal to the pressure of the air.

Upon these principles, the phenomena of boiling or ebullition are easily explained. When the temperature of a liquid is raised sufficiently high, vapor is rapidly generated from those portions of the mass which are hottest, and the violent motion characterized by the term "boiling" is the result. This is due to the fact that the elastic force of the generated vapor at that point is equal to the atmospheric pressure, and the vapor bubbles expanding, can maintain themselves in the liquid without being crushed in; they rise to the surface, and there burst. But, just before ebullition takes place, a singing sound is often heard, due to the partial formation of bubbles, which, so long as they are in the neighborhood of the hottest part, have elasticity enough to maintain their form; but the moment they attempt to rise through the cooler portion of the liquid just above, their elasticity is diminished by their decline of temperature, and the atmospheric pressure crushing them in, they resume the li-

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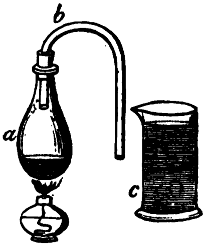
At the boiling point of water, what is the elastic force of its steam? Explain the phenomena of boiling. What is the cause of the singing sound?

quid condition; for a few moments, therefore, while the vapor has not gathered elastic force enough to maintain its condition perfectly, these bubbles are transiently formed and disappear, and the liquid is thrown into a vibratory movement which gives rise to the singing sound.

Water, when heated in a vessel from which the steam can not escape, never boils. This takes place in the interior of Papin's digester, which is a strong metallic vessel, in which water is inclosed, and the orifice through which it was introduced fastened up. As the steam can not escape, the water can not boil, no matter what the temperature may be. But the vapor which accumulates in the interior of the vessel exerts an enormous pressure. It is under the same conditions as were considered in the case of the candle bombs. Papin's digester is used to effect the solution of bodies by water which are not acted on readily by that liquid at its common boiling point.

Fig. 30.



As a vapor, rising from a vaporizing liquid, will bear no increase of pressure, so neither will it bear any reduction of temperature without instantaneously condensing. This may be strikingly shown by an arrangement such as is represented in *Fig.* 30. Into the mouth of a flask, *a*, let there be fitted a tube, *b*, half an inch in diameter, and bent, as shown in the figure. Having introduced a little water into the flask, cause it to boil rapidly by the application of a spirit lamp: the steam which forms soon drives out the atmospheric air from the flask and the tube, and when this is entirely completed, and the vapor issuing abundantly from the mouth of the tube, plunge the end of the tube beneath some cold water, contained in the jar, *c*, and take away the lamp. As soon as this is done, the cold water, condensing the steam in the tube, rises to occupy its place, and presently passing over the bend, introduces itself with surprising violence into the interior of the flask, filling it entirely full, or, which more commonly takes place, breaking it to pieces with the force of the shock. The low-pressure steam-engine depends on

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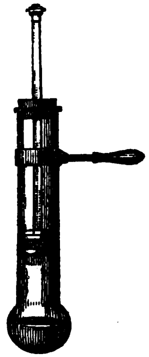
Why does water heated in a close vessel never boil? Describe Papin's digester. What is its use? Can the steam of boiling water be cooled without condensation? Give an example of the rapidity of its condensation.

this fact of the rapid condensibility of vapor, the high-pressure engine on its elastic force.

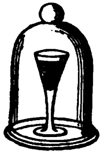
Fig. 31.



The principle involved in the action of the low-pressure engine, and more especially that form of it which was the invention of Newcomen, is well illustrated by the instrument represented in *Fig.* 31. It consists of a glass tube, blown into a bulb at its lower extremity. In the bulb some water is placed, and a piston slides, without leakage, in the tube. On holding the bulb in the flame of a spirit lamp, steam is generated, and the piston forced upward. On dipping it into a basin of cold water, the steam condenses, and the piston is depressed; and this action may be repeated at pleasure.

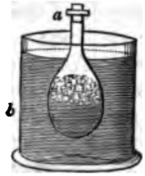
As the pressure of the atmosphere determines the boiling point of a liquid, and as that pressure is variable, the boiling point is not fixed, but a variable point. There are many experiments which might be introduced as proofs of this fact. If a glass of warm water be placed beneath the receiver of an air pump, as in *Fig.* 32, when the rarefaction has reached a certain point, ebullition sets in, and the water continues to boil at a lower temperature as the exhaustion is more perfect. In a vacuum, water can be made to boil at 32°.

Fig. 32.



On this principle, that the boiling point depends on the existing pressure, we give an explanation of a curious experiment, in which ebullition is apparently brought about by the application of cold: Take a Florence flask, *a*, *Fig.* 33, and, having filled it half full of water, cause the water to boil violently, so as to expel all the atmospheric air; introduce a cork which will fit the mouth of the flask air-tight a moment after it is moved from the lamp, and before any atmospheric air has been introduced. If the flask be now dipped into a jar, *b*, of cold water, its water begins to boil,

Fig. 33.



On what property of vapor does the low-pressure steam-engine depend? On what the high-pressure? How may it be proved that the boiling-point depends on the pressure? At what temperature will water boil in vacuo? Explain the process by which warm water may be made to boil by the application of cold.

and will continue to do so until its temperature is reduced quite low. The cause of this phenomenon is due to the fact that the cold water condenses the steam in the flask, and a partial vacuum is the result. In this partial vacuum the water boils, as in the experiment illustrated by *Fig.* 32; and the steam, as fast as it is generated, is condensed by the cold sides of the flask.

Besides this variation of the boiling point under variation of pressure, the nature of the vessel in which the process is carried forward exerts a certain action; thus, in a polished glass vessel, the boiling point is 214°, but in a rough metal vessel it is 212°. If the glass has been carefully cleaned with hot sulphuric acid, water may be heated to 221° without ebullition; and, on the contrary, if coated with a film of shell-lac, the boiling point will be 211°.

Some travelers report, that in certain mountainous regions meat can not be cooked by the ordinary process of boiling. As we ascend to elevated regions in the air, the atmospheric pressure becomes less, because the column of air above is shorter, and therefore there is less air to press. Under such circumstances, the boiling point of water of course descends, and may possibly become so low as to bring about the specific change required in the cooking of meat. An ascent through 530 feet lowers the boiling point one degree. Upon this principle we can determine the altitude of accessible elevations, by determining the thermometric point at which water boils upon them. A peculiar thermometer, called the hypsometer, has been invented for this purpose.

When a drop of water is placed on a red-hot polished surface of platinum, it does not, as might be expected, commence to boil rapidly, but remains perfectly quiescent, gathering itself up into a globule. If the platinum be now allowed to cool, as soon as its temperature has reached a point at which it has ceased to be visibly hot, the drop of water is suddenly dissipated in a burst of steam. The explanation given of this phenomenon is, that at the high temperature the drop is not fairly in contact with the red-hot surface, but a stratum of steam intervenes; this, being

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How does the nature of the vessel affect the boiling point? Why is it probable that meat can not be cooked on high mountains? How high must we ascend to bring the boiling point to 211°? How may the altitude of mountains be determined by the thermometer? What are the phenomena exhibited by water in contact with red-hot platinum? What is the supposed explanation?

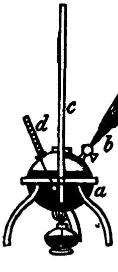
a bad conductor, prevents ebullition from occurring, but as soon as the temperature declines, and this steam no longer props up the drop, an explosive ebullition ensues, because of the contact which has taken place. This condition is known as the spheroidal state of a liquid. Water enters upon it at temperatures between 288° and 340° of the hot surface, its own temperature being about 206°. It is said to be in consequence of this want of actual contact that the hand can be passed through red-hot and molten metal without being burned.

LECTURE XII.

VAPORIZATION.—*The Boiling Point rises with the Pressure.—Relation between sensible and insensible Heat.—The Cryophorus.—Leslie's Process for freezing Water.—Variability of Moisture in the Air.—Hygrometers.—Method of the Dew Point.*

UNDER an increase of pressure, the boiling point rises, and the elastic force of the steam evolved becomes correspondingly greater. As we have seen, the elastic force of steam from water boiling at 212° is equal to the pressure of one atmosphere; but if the pressure be doubled, the boiling point rises to 250°; if quadrupled, to 294°; and under a pressure of fifty atmospheres, it is more than 500°.

Fig. 34.



These results may be established by the aid of the boiler, represented in *Fig.* 34, *a*. It is a globular vessel of brass, and is about three inches in diameter. In its upper part are three perforations, into one of which the stop-cock, *b*, is screwed; through the second a tube, *c*, is inserted, deep enough to reach nearly to the bottom of the boiler; and through the third a thermometer, *d*, is introduced. Some quicksilver is poured in, sufficient to cover the end of the tube, *c*, half an inch or more deep, and upon it water is poured, the bulb of the thermometer being immersed in it. The stop-cock, *b*, being open, a spirit lamp is applied to bring the

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How is the boiling point affected by an increased pressure? Describe the boiler, *Fig.* 34, and its use.

water to its boiling point, and as the steam can freely pass out, this of course takes place at 212°. On closing the stop-cock, the steam can no longer escape, but, exerting its elastic force on the surface of the boiling liquid, presses the mercury up in the tube, *c*. The altitude of the mercurial column measures the amount of this pressure, and the thermometer indicates the corresponding change in the boiling point: as soon as the pressure is equal to two atmospheres, the thermometer will be found to have risen to 250°.

It is immaterial at what temperature vaporization is carried on, a very large amount of heat must always be rendered latent; and, in point of fact, vapors generated at a low temperature contain more latent heat than those generated at a high one. The relation which exists in the amount of heat rendered latent at different temperatures is very simple. The sum of the insensible and sensible heat is always the same; thus, water boiling at 212° absorbs 1000° of latent heat, the sum of the two quantities being of course 1212; but vapor rising from water at 32° contains of latent heat 1180°; here, again, the sum of the two quantities is 1212°; and the same observation holds for intermediate temperatures.

When vapors return to the liquid condition, the heat which has been latent in them reassumes the sensible form. They may thus be regarded as containing a great store of caloric, of the effects of which many natural phenomena furnish us with striking examples. Thus, there is a remarkable difference between the climate of the eastern coast of America and the opposite European coasts in the same latitude, and this arises from the action of the Gulf Stream, a great stream of warm water, which, issuing from the Gulf of Mexico, and passing the Atlantic States, stretches across toward the European Continent. The vapors which arise from it give forth their latent heat to the air, and the southwest winds, which are therefore damp and warm, moderate the climates of those countries.

The cryophorus, or frost bearer, an instrument invented by Dr. Wollaston, in which water may be frozen by the cold produced by its own evaporation, depends for its action on

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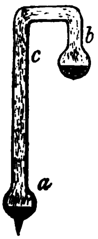
Do vapors generated at low or high temperatures contain most latent heat? What relation is there between the insensible and sensible heats of vapors at different temperatures? When a vapor condenses, what becomes of its latent heat? What effect has the Gulf Stream on the climate of Europe? Explain the cause of it.

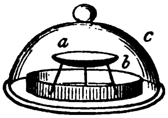
Fig. 35.



the laws relating to latent heat. It is represented in *Fig.* 35, and consists of a bent tube, *c*, half an inch or more in diameter, with a bulb, *a* and *b*, at each of the extremities; the upper bulb, *b*, is filled one third with water, and the rest of the space, with the tube, *c*, and the other bulb, *a*, is free from atmospheric air, and occupied by the vapor of water only. If now the bulb *a* be immersed in a freezing mixture of nitric acid and snow, although the tube, *c*, may be of considerable length, the water in the distant bulb, *b*, presently freezes; hence the name of the instrument, frost bearer, because cold applied at one point produces a freezing effect at another, which is at a considerable distance. The action of the instrument is simple: in the cold bulb, *a*, which is in contact with the freezing mixture, the vapor is condensed; fresh quantities rise with rapidity from the water in the other bulb, to be in their turn condensed; a continual condensation, therefore, goes on in *a*, and a continual evaporation in *b*, but the vapor thus formed in *b* must have caloric of elasticity; it obtains it from the water from which it is rising, the temperature of which therefore descends until solidification takes place.

Leslie's process for freezing water in vacuo by its own evaporation is an example of the same kind. If some water in a watch-glass is placed in an exhausted receiver, with a large surface of sulphuric acid, as fast as vapor rises it is condensed by the acid; a rapid evaporation of the water therefore takes place, the temperature falls, and congelation finally ensues. In *Fig.* 36 this apparatus is represented; *a* is the watch-glass containing water, *b* a wide dish filled with sulphuric acid, and *c* a low bell jar in which the exhaustion is made.

Fig. 36.



A drop of prussic acid held in the air on the tip of a rod solidifies, the portion that evaporates obtaining its latent heat from the portion left behind, and on the same principle liquid carbonic acid can also be solidified.

The amount of watery vapor contained in the air is very variable. Many common facts prove this: the swelling of

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Describe the cryophorus. What is the reason that cold applied to one bulb freezes water in the other? Describe Leslie's process for freezing water in vacuo? Why does a drop of prussic acid held in the air solidify?

wooden furniture takes place in consequence of damp weather; and the opposite effect, or its shrinking, occurs during dry. Several instruments have been invented to determine what the amount is at any time; they are called hygrometers. In one of these, the relative dampness or dryness of the atmosphere is determined by the stretching or contracting of a hair, which is very sensitive to such changes. A general idea of such an instrument may be obtained by considering the metallic bar of the pyrometer, *Fig.* 15, to be replaced by a hair, the movements of which would of course be communicated to the index; in another a slip of whalebone is used instead of the hair.

Saussure's hygrometer, which is constructed on these principles, has been very extensively used. It consists of a human hair eight or ten inches long, *b c*, *Fig.* 37, fastened at one extremity to a screw, *a*, and at the other passing over a pulley, *c*, being strained tight by a silk thread and weight, *d*. From the pulley there goes an index, which plays over the graduated scale, *e e′*, so that, as the pulley turns through the shortening or lengthening of the hair, the index moves. The instrument is graduated to correspond with others by first placing it under a bell jar, with a dish of sulphuric acid or other substance having an affinity for water, which, absorbing all the moisture of the air of the bell, brings it to absolute dryness. The point at which the index then stands is marked 0. The hygrometer is next placed in a jar, the interior of which is moistened with water; when the index has again become stationary, the point is marked 100°, and the intervening space divided into 100 equal parts.

Fig. 37.

The hair should have its oily matter removed by soaking in sulphuric ether. This preparation renders it much more sensitive.

There is a simple and ingenious instrument, the movements of which depend on these principles; it is represented in *Fig.* 38: a thin slip of pine wood, *a a*, cut across the grain, a foot long and an inch wide, has inserted into its corners four needles, all pointing in one

Fig. 38.

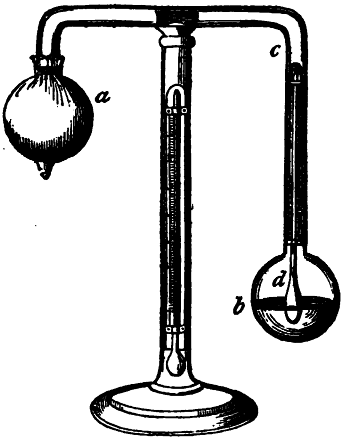
How can it be proved that the amount of moisture in the air is variable? What is the hygrometer? Describe the hair hygrometer. Describe the instrument, *Fig.* 38.

direction backward; if this instrument be set upon a floor or flat table, in the course of time it will crawl a considerable distance. During dry weather the thin board contracts, and the two fore legs taking hold of the table, the hind ones are drawn up a little space; when the weather turns damp, the board expands, and now the hind legs, pressing against the table, cause the fore ones to advance. Every change from dry to damp, or the reverse, produces a walking motion in a continuous direction, and the distance passed over is a register of the sum total of these changes.

But of all these hygrometric methods, the process known as "the determination of the dew point" is by far the most philosophical. This method consists in cooling the air until it begins to deposit moisture. When there is much moisture in the air, it obviously requires but a slight diminution of temperature to cause a portion of the vapor to deposit as a dew; but when the air is dryer, the cooling must be carried to a greater extent. The precise thermometric point at which the moisture begins to deposit is called the dew point.

Thus, if we take a thin metallic vessel containing water, and cool it gradually by the addition of a mixture of nitrate of potash and sal ammoniac, or any of the cooling mixtures, continually stirring with the bulb of a small thermometer, as soon as the temperature has reached a certain point a dew is deposited on the outside of the metallic vessel; that temperature is the dew point for the time being. Knowing the temperature of the air, the dew point, and the barometric pressure, the absolute amount of vapor can be determined by a simple calculation.

Fig. 39.



Daniell's hygrometer affords a ready and beautiful method of determining the dew

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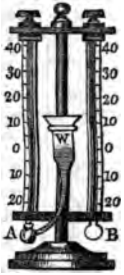
What is meant by the "dew point?" What is the process for ascertaining it?

point. It consists of a cryophorus, *a c b*, *Fig.* 39, the bulb *b* being made of black glass, and *a* covered over with muslin. The bulb *b* contains ether instead of water, and into it there dips a very delicate thermometer, *d*. Usually, another thermometer is affixed to the stand of the instrument. When a little ether is poured on *a*, by its evaporation it cools that bulb, and ether distils over from *b*, which, of course, also becomes cold. After a time, the temperature of *b* sinks to the dew point, and that bulb becomes covered with a dew. The thermometer, *d*, then shows at what temperature this takes place, and of course gives the dew point.

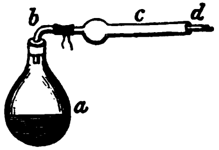
The Psychrometer, or wet bulb hygrometer, consists of two mercurial thermometers which exactly correspond; the bulb of one of them, A, *Fig.* 40, is covered with muslin, and kept constantly wet by water supplied by a thread from a reservoir, W. The bulb, B, of the other is left naked. Owing to the evaporation from the wet bulb, its temperature will be lower than the dry one, and this in proportion to the rate of evaporation or the dryness of the adjacent air. As soon as the air round the bulb is saturated with moisture, the point at which the mercury stands is the dew point. If both thermometers, the wet and the dry, coincide, the air contains moisture at its maximum density; and the greater the difference between them, the dryer the air.

Fig. 40.



It is frequently necessary to remove moisture from air or gaseous substances. This may be done by conducting them through tubes containing bodies having a strong attraction for water, such as chloride of calcium, sulphuric or phosphoric acids. Such an arrangement is shown in *Fig.* 41, in which *a* is the flask in which the gas is generated, *b* a bent tube connecting with the drying tube, *c*, which is filled with fragments of chloride of calcium, or pieces of glass moistened with concentrated sulphuric acid. The gas escapes dry from the tube, *d*.

Fig. 41.

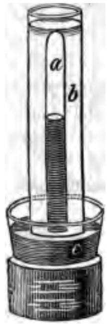


Describe Daniell's hygrometer and the mode of using it. Describe the process for drying gases.

LECTURE XIII.

EVAPORATION AND INTERSTITIAL RADIATION.—*Methods of Gay-Lussac and Dumas for ascertaining the Specific Gravity of Vapors.—Phenomena of Evaporation.—Control of Temperature.—Effect of Dryness, Stillness, Pressure, and Surface.—Evaporation a Cooling Process.—Conduction of Solids.—Difference among different Metals.—Rumford's Experiments.*

Fig. 42.



THE specific gravity of vapors may be determined in several ways. The following is the method of Gay-Lussac: A graduated jar, *a*, is inverted in a basin of mercury, *c*, which rests upon a small furnace. A glass bulb is to be filled quite full with the liquid under examination, and the quantity introduced is accurately weighed. The bulb is now slipped into the jar, *a*, and rises to its top. A cylinder, *b*, open at both ends, but the lower pressed down into the mercury, is next placed round *a*, and the interval filled with clear oil. The furnace is now lighted; the oil and the mercury become warm; the bulb at last bursts, and, as its vapor depresses the mercury in the graduated jar, its volume may be determined. Thus, knowing the weight of the liquid, the volume of its vapor, and the temperature of the oil, we can easily calculate the volume at 32°, and from that deduce the specific gravity.

The method of Dumas consists in weighing a glass globe filled with the vapor to be tried. A portion of the substance is to be introduced into the globe, the weight of which is *first* determined, and this is then held, as shown in the figure, in a bath of fusible metal placed over a small furnace. The heat of the melted metal vaporizes the substance, drives out the air, and occupies the whole cavity in a state of purity. When no more vapor escapes from the end of the tube, it is sealed by the blow-pipe, and the temperature of the bath ascertained. The globe is now to be

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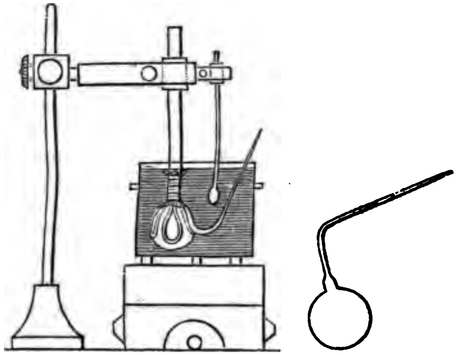
Describe Gay-Lussac's method of determining the specific gravity of a vapor. Describe the method of Dumas.

carefully weighed, when cold, a *second* time, and the point of the tube is then broken under quicksilver, which rises and fills it completely, and this being subsequently emptied into a graduated jar, the volume of the globe is ascertained. Knowing the volume of the globe, we know the weight of the air it contains, and this, subtracted from the first weight, is the weight of the glass when empty. Subtracting this again from the second weighing, gives us the weight of the vapor; and as the air and the vapor occupied the same volume, their densities are as their weights. But, as their temperature was different, a farther calculation is required to bring them to the same standard.

Fig. 43.



There are several conditions which exert a control over the rapidity of evaporation. The amount of vapor which can exist in a given space depends entirely on the temperature. Thus the air included in a glass jar which is standing over water contains, at 32°, a certain quantity of vapor; but if the temperature rises to 60°, it contains more, and still more if it rises to 90°. Should the temperature descend, a part of the vapor is deposited as a mist. The quantity that remains in suspension is determined by the temperature alone.

It is the application of this principle which constitutes the most beautiful part of Watt's great invention, the low-pressure steam-engine. Taking advantage of the fact that the quantity of vapor which can exist in a given space is determined by the lowness of temperature of any portion of it, he arranged a vessel, maintained uniformly at a low temperature, in connection with the cylinder of the engine, and

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What is it that regulates the quantity of vapor in a given space? On what principle does the steam-engine condenser depend?

thus reached the apparently paradoxical result of condensing the steam without cooling the cylinder.

Among other causes exerting a control over evaporation in the air is the dry or damp state of that medium. As is well known, evaporation goes on with rapidity when the weather is dry, and is greatly retarded when the weather is damp. So, too, a movement or current exerts a great effect. When the wind is blowing, water will evaporate much more quickly than when the air is quite calm; this obviously depends on a constant renewal of surfaces, so that as fast as one portion of air becomes moist it is removed, and a dryer portion takes its place. Extent of surface operates in the same way; the same quantity of water will evaporate much more rapidly if exposed in a plate than if exposed in a cup. Pressure also exerts a great control; for, as we have seen, evaporation takes place instantaneously in a vacuum.

While, therefore, there are several circumstances which can control the rate of evaporation, it is temperature alone which regulates the absolute and final amount. As we have just seen, a fixed quantity of vapor can exist in a certain space at a given temperature; and it matters not whether that space is full of atmospheric air or is a vacuum, the absolute quantity will be precisely the same.

At one time it was supposed that evaporation was due to a solvent power in the air—a kind of attraction between that medium and the water with which it is in contact; but it is clear that such an opinion is wholly untenable, for the process goes forward with the greatest rapidity in a vacuum, when the air is totally removed.

Although the evaporation of liquids, such as water, will take place at very low temperatures, there is reason to believe that the process has a limit; thus, a minute quantity of vapor will rise from quicksilver at a temperature of 60°, but at 40° not a trace can be discovered.

All processes of evaporation are cooling processes, because the vapor developed requires latent heat to give it the elastic form. For this reason, when any vaporizable liquid, as ether, is poured on the bulb of an air thermometer, or on the hand, cold is produced.

What effect have dryness or dampness over evaporation? What is the effect of a current? What of extent of surface? What of pressure? What of temperature? Does evaporation arise from a solvent power in the air? Is there any limit to evaporation? Why are processes of evaporation cooling processes?

The pulse glass is an instrument which may serve as an illustration: it consists of a glass tube, bent twice at right angles, and terminated by bulbs, as in *Fig.* 44. It is partially filled with spirit of wine, the rest being occupied by the vapor of that substance. On grasping one of the bulbs in the hand, the warmth is sufficient to boil the liquid; and as it distills over into the other bulb, an impression of cold is felt.

Fig. 44.

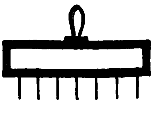
INTERSTITIAL RADIATION OR CONDUCTION.

We now come to the consideration of the mode by which heat is transmitted through bodies, or interstitial radiation, called by many writers conduction; a term involving the idea that the particles of bodies are in actual contact, whereas it has been abundantly proved that they are separated from each other by interstices. The passage of the heat across these spaces is what is meant by interstitial radiation. From the currency which it has obtained, and the convenience of the expression, I shall continue to use the word conduction.

Different solids conduct heat with different degrees of facility. If we take a cylindrical mass of metal, and hold tightly against its surface a piece of white writing paper, the paper may be placed in the flame of a spirit lamp for a considerable time without scorching; but if we take a cylindrical piece of wood of the same dimensions, and, wrapping the paper round it, expose it to the flame, it rapidly scorches. The metal, therefore, keeps the paper cool by carrying off its heat, but the wood, being a bad conductor, suffers the paper to burn.

By the aid of the apparatus of Ingenhouse, *Fig.* 45, the same fact may be proved in a more general way. It consists of a trough of brass six inches or more long, three wide, and three deep; from the front of it project cylinders of metallic and other substances of the same length and diameter; they may be of silver, copper, brass, iron, porcelain, wood, &c., in succession; the

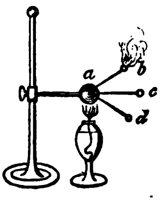
Fig. 45.



Describe the pulse glass. What is interstitial radiation? What is conduction? How may it be proved that wood and metals conduct with different degrees of facility? Describe the apparatus of Ingenhouse?

surface of each cylinder is smeared with bees' wax. On pouring boiling water into the trough, the heat passes along these cylinders with a rapidity corresponding to their conducting power, and the wax correspondingly melts. On the silver bar the wax melts most rapidly, and on the wood most slowly; on the others intermediately; thus affording a clear proof that different solids conduct heat with different degrees of facility.

Fig. 46.



Even among metallic substances great differences in this respect exist, as may be strikingly shown by the instrument, *Fig.* 46. Into a solid ball of copper, *a*, three wires of equal length and equal diameter are screwed—they may be copper, brass, and iron respectively: they are flattened at their farther extremities, *b*, *c*, *d*, so as to afford a place on which pieces of phosphorus may be put. A lighted spirit lamp is now set beneath the central ball, the temperature of which soon rises, and the heat passes with different degrees of speed along the metals; very soon the piece of phosphorus at the end of the copper takes fire; then, some time after, follows that on the brass; and last, that on the iron; enabling us to prove to persons at a distance the fact that these different metals conduct heat with different degrees of facility.

Table of Conducting Power of Solids.

Gold	1000	Tin	303·9
Silver	973	Lead	179·6
Copper	898	Marble	23·6
Iron	374·3	Porcelain	14·2
Zinc	363	Clay	11·4

If a piece of wire gauze be held over the flame of a candle or gas jet, *Fig.* 47, the flame fails to pass through; but the gaseous matter of which the flame consists freely escapes through the meshes of the gauze, for it may be set on fire, as shown in the figure. Flame is gaseous matter, or solid matter in a state of excessive subdivision, temporarily suspended in gas, brought to a very high temperature. It can not, therefore, pass through a piece of wire gauze, because

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What does it prove? Are there differences in the conducting powers of metals? How may that be proved? Can the flame of a candle pass through a piece of wire gauze?

Fig. 47.

the metallic threads, exerting a high conducting power, abstract its heat from the incandescent gas, and bring its temperature down to a point at which it ceases to be luminous. The safety-lamp of Davy is an application of this principle; by it combustion is prevented from spreading through masses of explosive gas, by calling into action the conducting power of a metallic gauze, with which the lamp frame is surrounded, as in *Fig.* 48. The safety-tube of Hemmings, used to prevent explosions in the oxyhydrogen blow-pipe, acts on the same principle.

Fig. 48.

Count Rumford made several experiments to determine the conducting power of those various materials which are used for the purpose of clothing. He placed the bulb of a thermometer in the centre of a spherical glass globe of larger diameter, and filled the interspace with the substances to be tried. Having immersed the apparatus in boiling water until it was at 212°, he transferred it to melting snow, and ascertained how long it took to fall a given number of degrees. Linen and cotton were found to be better conductors than wool and the various furs, and hence the reason that they are preferred as articles of summer clothing; but he also found that much depended on the tightness with which the substances were packed, for the conducting power apparently rose when they were closely compressed. These bodies act, therefore, as will hereafter be more distinctly seen, not so much by their own badly-conducting power, as by calling into action the non-conducting quality of atmospheric air.

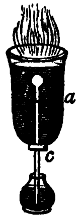
Crystalline bodies do not always conduct equally in every direction. If a plate cut from a rhombohedral crystal be warmed from a point at its centre, the surface having been previously coated with wax, it will be found that the fusion of the wax takes place so as to present an ellipse, the longer axis of which is in the direction of the major crystalline axis.

What is the reason of this? What is the construction and principle of Davy's safety-lamp? On what method did Rumford proceed to determine the conducting power of clothing? What was the effect of compression? How are these results connected with the non-conducting power of air?

LECTURE XIV.

CONDUCTION.—*Conduction of Liquids.—Transference of Heat by Circulation.— Conduction of Gases.— Conducting Power of Clothing.*

Fig. 49.



THE conducting power of most liquids, such as water, is very low; a thin stratum is sufficient almost entirely to cut off the passage of heat. This may be shown by an apparatus such as *Fig.* 49, consisting of a jar, *a*, nearly filled with water, with an air thermometer included in such a manner that the bulb, *b*, is within a short distance of the surface, a depth of a quarter of an inch or less intervening. The tube of the thermometer may be passed through the lower mouth of the jar, *c*, water-tight by means of a cork, and the position at which the index-liquid stands having been marked, some ether is poured on the surface of the water, upon which it readily floats, and then set on fire. A very voluminous flame is the result, and a great deal of heat is evolved; and, since the bulb of the thermometer is apparently separated from the burning ether by a thin film of water only, if the heat traversed that film the thermometer should rapidly move; but the experiment proves it does not; and we therefore conclude that water is a very bad conductor of caloric.

While this conclusion is true, a little consideration will show that this experiment presents the facts in a very deceptive way; and though, from its imposing character, it is generally relied on as a complete proof, yet, were water a much better conductor than what it actually is, the same results would be obtained. All flames, as we shall hereafter see, are hollow; they are merely incandescent on the surface. A great distance, in reality, intervenes between the thermometer bulb and the points of high temperature, and, in addition, the ether is rapidly evaporating away to feed the flame, and all evaporations are cooling processes..

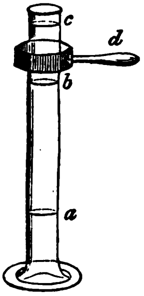
To a certain extent, all liquids conduct heat: thus, mer-

How does the conducting power of liquids compare with that of solids? How may water be proved to be a bad conductor? What deceptive circumstances are there in this experiment? Do liquids conduct heat at all?

cury is a very good conductor; but in those liquids of which water is the type, the dissemination of heat is chiefly determined by the mobility of their particles, a process which passes under the name of convection or circulation.

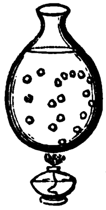
The apparatus, *Fig.* 50, illustrates the nature of this process: it consists of a wide tube into which water may be poured; the lower portion, as high as *a*, being colored blue by the addition of some coloring substance, the intermediate portion, from *a* to *b*, being colorless, and the upper portion, from *b* to *c*, being tinged yellow. Now, by the application of a red-hot iron ring, *d*, of such a diameter that it can surround the jar, a space of an inch or more intervening all round, the upper, yellow portion may be made even to boil: it shows no disposition to intermix with the portions beneath. But if the red-hot ring is lowered down so as to surround the blue portion, as it becomes warm it will be found to ascend, first through the colorless stratum, and finally through that tinged yellow, on the top. When the lower portion of a liquid is warmed, currents are established, which, rising through the strata above, bring about a rapid dissemination of the heat.

Fig. 50.



This may also be shown by taking a jar, *Fig.* 51, *a*, and filling it with water, rendered a little more dense by some sulphate of soda, so as to bring its specific gravity near that of some pieces of amber thrown into it. If a lamp now be applied to the bottom of the jar, currents are established in the water, rising up the center and descending down the sides of the liquid; and in this manner, new portions constantly presenting themselves on the surface exposed to the flame, the whole mass becomes uniformly hot.

Fig. 51.



The cause of this movement is due to the fact that when water is heated it expands. Those portions, therefore, which rest on the bottom of the vessel, and to which the heat is applied, as soon as they become warm, dilate, and, being

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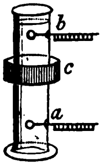
What are the relations of mercury in this respect? By what process does the dissemination of heat in a liquid take place? Describe the experiment represented in *Fig.* 50. Describe that represented by *Fig.* 51. What is the true cause of these circulatory movements?

lighter than before, rise to the top of the liquid, while colder, and therefore heavier ones, occupy their place.

Fig. 52.



If we take a jar of water, *Fig.* 52, and having introduced through apertures near the top and the bottom the thermometers *a b*, and into a brass trough, *c*, which surrounds the middle of the jar water-tight, pour boiling water, after a little time has elapsed we shall find that the upper thermometer has risen, but the lower one remains perfectly stationary. The cause is, that through all those portions which are above the place at which the heat is applied, that is, the middle of the vessel, currents are made to circulate, but in all those beneath no currents are established.

When, therefore, heat is applied to the surface of water, it is not propagated downward; when it is applied to the middle of a vessel containing that liquid, all the portions above become hot, but all those below remain cold; and when it is applied to the bottom of the vessel, the whole mass soon becomes uniformly warm.

In the vegetable world, advantage is taken of the non-conducting power of water in a very beautiful way. Soon after sunset, the leaves and other delicate parts of plants become covered with little drops of dew, which invest them on all sides. Under these circumstances, the process of convection, or the establishment of currents, is entirely cut off, for each of the drops is isolated, or has no communication with those around. The cold air does not so suddenly affect these delicate organs as it would do were not this thin non-conducting film spread over them; their action is, therefore, less liable to be deranged.

Recent accurate experiments show that all liquids conduct to a certain extent, though in many instances to a far less extent than what we see in the case of solid bodies. Among different liquids, difference in conducting power has also been discovered.

If the conducting power of liquids is small, that of gaseous bodies is still less perceptible. In these, as in liquids, the mobility of the particles is so great that heat is readily

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How can it be proved that the warm water floats on the surface of that which is cold? What is the effect of applying heat to the top, to the middle, and to the bottom of a vessel containing water? What advantage is taken in the vegetable world of the non-conducting power of water? Do all liquids conduct heat? Are there differences in their conducting power?

diffused through them. Thus, if we take a jar, *Fig.* 53, containing oxygen gas, and place a piece of burning sulphur in it on a stand, *a*, the vapor which rises from the sulphur moves in a current to the top of the jar, and then descends in beautiful wreaths of smoke down the sides, precisely representing the circulatory movements of liquids.

Fig. 53.

The ventilation of buildings and mines, and the proper construction of furnaces and chimneys, depend upon these principles.

By taking advantage of the non-conducting power of air, rooms may be kept warm with a small consumption of fuel, by furnishing them with double windows. A stratum of air, two or three inches thick, intervening between the windows, effectually cuts off the passage of heat. It is upon the same principle we explain Count Rumford's experiments in relation to the conducting power of clothing; he found that when the same fibres are used, the apparent facility with which they transmit heat depends on the closeness with which they are packed: the non-conducting power of air is here evidently called into play, and the fibres act by preventing the production of currents. In the case of sheep or other animals, which during the winter season are covered with a thick coat of wool or fur, it is the non-conducting power of the included air which is again brought into operation.

LECTURE XV.

Radiation.—*Preliminary Ideas on Radiant Heat.—Analogies with Light.—Effect of Surfaces.—Relations between Radiation and Reflection.—The Florentine Experiment.—The Cold-ray Experiment.—Opacity of Glass to Heat.—Its increasing Transparency as the Temperature rises.—Properties of Rock Salt.*

But, though gases are bad conductors of heat, they free-

By what process is heat diffused through gases? What is the use of double windows? What connection has the non-conducting power of air with Count Rumford's experiments? In the economy of animals, what advantage is taken of these principles?

ly allow of its transmission by radiation. A person who stands at one side of a fire receives the heat of it, although no currents of warm air can reach him. In a vacuum, a piece of red-hot metal rapidly cools.

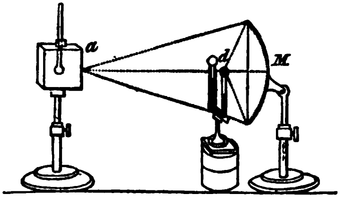
The heat which, under these circumstances, escapes from bodies is entirely invisible to the eye; it moves in straight lines, exhibiting many of the phenomena of the rays of light. Thus, if we interpose between a fire and a thermometer an opaque screen, the moment the rays of light are stopped the heat is simultaneously intercepted.

The rays of heat, like the rays of light, are capable of being reflected by polished metallic surfaces. If a piece of planished tin be held before a fire in such a position as to reflect the light of it upon the face, the heat, also, is similarly reflected, and gives rise to a sensation of warmth.

The analogy between light and heat is farther observed when rays of the latter fall upon bodies of a different physical constitution from the metals. As glass is transparent to light, there are many bodies transparent to rays of heat, though, as we are presently to find, these bodies are not the same in both instances. And as there are substances, like lamp-black, which will absorb all the light which impinges on them, there are many which perfectly absorb heat: reflection, transmission, and absorption are therefore common to both these agents.

If we take two metallic vessels of the same size and shape, and having blackened one of them all over with the smoke of a candle, fill them both with hot water, and notice their rate of cooling, it will be seen that the blackened one cools faster; the same thing may be observed if, instead of blackening the vessel, it is covered with layers of varnish. These results may be proved by the aid of Leslie's canister, which consists of a cubical brass vessel, *a*, *Fig.* 54, set upon a vertical stem, upon which it can rotate; at a little distance is

Fig. 54.



Do gases transmit radiant heat? How may it be proved that radiant heat moves in straight lines? Is it capable of reflection? Are there any substances transparent to radiant heat? Are these the same bodies that are transparent to light? Of two surfaces, one polished and the other blackened, which radiates heat best?

placed the blackened bulb of a differential thermometer, *d;* a mirror, *M*, receives the rays of the canister and reflects them on the thermometer. One of the vertical sides of the cube is left with a clear metallic surface, a second washed over with one coat of varnish, the third with two, and the fourth with three coats; if these sides be presented in succession to the thermometer, they will be found to radiate heat with very different degrees of speed, more heat escaping from them as the number of coats is increased. In the experiments of Melloni, it was found that the maximum was not attained until sixteen coats were applied.

These results can only be explained on the principle that radiation does not take place from the surface of bodies merely, but from a certain depth in their interior.

A highly-polished metal is a bad radiator, but on roughening the surface, its quality is improved. As a general rule, good radiators are bad reflectors, and good reflectors are bad radiators.

When rays of light, diverging from the focus of a concave parabolic mirror, impinge on the surface, they are reflected in parallel lines; when parallel rays fall on such a surface, they are reflected to its focus. Thus, if from the point, *a*, *Fig.* 55, the focus of a parabolic concave, *c f*, rays diverge, they will be reflected in parallel lines, *c g*, *d h*, *e i*, *f k*, and if at these points they be intercepted by the mirror, *g k*, they will be reflected to its focus, *b*.

Now, as the laws of reflection of radiant heat are the same as the laws of the reflection of light, it is plain that if we place any incandescent body, such as a red-hot cannon-ball, in the focus, *a*, the heat which radiates from it will finally be found at the other focus, *b*.

This is beautifully illustrated by an experiment known under the name of the experiment with conjugate mirrors. In the focus, *a*, *Fig.* 55, of a parabolic mirror, *c f*, place a red-hot cannon-ball, and in the focus, *b*, of a second mirror, *g k*, set opposite, but twenty or thirty feet off, place a piece

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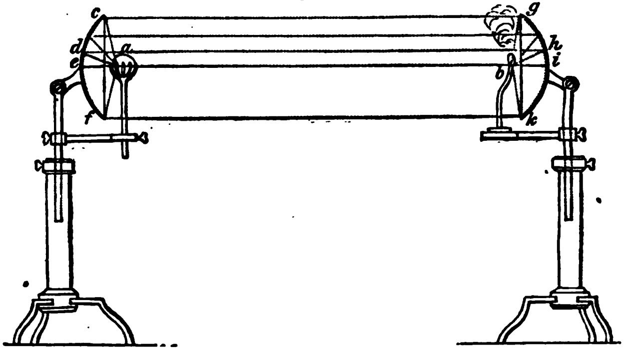
When successive layers of varnish are put on a surface, what is their effect? When is the maximum reached? What is the explanation of these results? What is the general connection between radiation and reflection? When rays diverge from the focus of a concave mirror, what is their path after reflection? When parallel rays fall on a concave mirror, what is their path after reflection? When a hot ball is placed in the focus of one of the mirrors, to what point does its heat converge? Describe the Florentine experiment represented in *Fig.* 55.

of phosphorus, a screen intervening between. As soon as the arrangements are completed, remove the screen, and in

Fig. 55.



a moment the phosphorus takes fire. That this effect is due to the reflecting action of the mirrors, as has been described, may be proved by removing the mirror, *c f*, when it will be found that the phosphorus can not be lighted, even though the ball be brought within a very short distance of it.

This striking experiment proves, first, that the rays of heat move in straight lines, like those of light; and, second, that in the same manner they are subject to the ordinary laws of reflection.

A variation of the foregoing experiment may be made by using a snowball instead of the cannon-shot, in which case a thermometer placed in the focus of the opposite mirror will exhibit a reduction of temperature. From this it was at one time supposed that there existed rays of cold precisely analogous to rays of heat, and that they observed the same law as respects the rectilinear nature of their movement, and were also subject to the law of reflection; but, as we shall see when we come to speak of the Theory of the Exchanges of Heat, a simple explanation of the whole result can be given, without implying the existence of a principle of cold analogous to the principle of heat.

Let it be now supposed that in the focus of the mirror, *g k*, ***Fig.*** 55, the bulb of a delicate thermometer is placed, and in the focus of the other mirror, *c f*, a metalline mass, *a*,

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What two facts does this experiment prove? When a snowball is used instead of a hot shot, what is the result?

the temperature of which we can vary at pleasure. Between the mirrors let there be interposed a screen of transparent plate glass; and let us farther suppose that the temperature of *a* is 212°, or considerably below the point at which it is visibly red hot. Under these circumstances the thermometer exhibits no rise of temperature so long as the glass intervenes, but the moment it is removed the heat passes.

A piece of transparent glass is therefore opaque to the rays of heat which come from a non-luminous source.

Let us now suppose that the temperature of the metalline mass, *a*, continually rises. When it has reached a red heat, a certain proportion of the rays emitted by it begins to pass through the glass, as is shown by their effect upon the thermometer. When the mass is visibly red hot in the daylight, the rays go through the glass more readily, and when it has become white hot, or has reached the highest temperature we can give it, the glass transmits the rays with facility.

These facts are of the utmost importance. They show that bodies transparent to light are not necessarily transparent to heat, and, therefore, that light and heat are separate and independent agents. They farther show that, as respects glass, its transparency for heat differs with the temperature of the source from which the rays come.

There is a certain well-known substance, rock salt, with which, if we could obtain plates large enough to intervene completely between the two mirrors, a different series of results would be exhibited. Whatever might be the temperature of the source, whether low or high, the rays would pass it with equal freedom. The warmth of the hand and the rays from melting iron would go through it alike. This substance, therefore, is permeable to all kinds of heat, as glass is permeable to all kinds of light. It constitutes the true glass for heat.

The great conclusion which we draw from the experiments just described is, *that there are different varieties of radiant heat*. Some of them can pass through glass, and some can not. Hereafter we shall see that the intrin-

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What is the relation of glass to radiant heat of low intensity? What changes take place in the transmissive power of the glass as the temperature rises? How are these facts connected with the physical independence of light and heat? What are the properties of rock salt? Why is it the glass of heat? What general conclusion is drawn from the foregoing facts?

sic differences in radiant heat are due to the same cause which gives different colors to light.

LECTURE XVI.

THEORY OF THE EXCHANGES OF HEAT.—*Physical Independence of Light and Heat.—Theory of Exchanges.—Explanation of the Cold Ray Experiment.—Wells's Theory of the Dew.—Cold on Mountain Tops.—Conduction a Form of Radiation.— Temperature of the Sun.*

THE earlier writers on chemistry supposed that if light and heat are not the same principle, they are mutually convertible; that when the rays of light fall on any object and warm it, they do so because they become extinguished and changed into heat.

But there are many facts which militate against this doctrine. A vessel containing hot water radiates heat, and that heat is totally invisible in a dark room, nor can it be made to assume the luminous condition, even though concentrated by large concave mirrors.

In addition, as we have already shown, the relation of transparency for these two agents is not the same. A piece of smoky quartz, or dark-colored mica, of such a degree of opacity as scarcely to admit a ray of light to pass, is freely traversed by radiant heat.

THEORY OF THE EXCHANGES OF HEAT.

The theory of the exchanges of heat, comprehending an explanation of a great number of the phenomena we ordinarily witness, depends upon the following principles: It assumes, 1st, that all bodies, no matter what their temperature may be, are constantly radiating heat at all times; 2d. That the rate of radiation depends on the temperature, increasing as the temperature rises, and diminishing as it declines.

What are the varieties of radiant heat due to? What relation was formerly supposed to exist between light and heat? Can rays of heat exist without being visible? Can light exist unaccompanied by heat? What other evidence have we of the physical independence of these agents? On what does the theory of the exchanges of heat depend?

Thus the various objects around us are constantly emitting caloric, the warm bodies to the cold, and the cold ones to the warm. A mass of snow and a red-hot cannon-ball respectively give off heat, the ball emitting it in great quantities, and the snow in less. And even when adjacent bodies have reached the same thermometric point, they still continue to exchange heat with one another.

Upon these principles, we can readily account for the fact that bodies of different temperatures at first, finally come to an equilibrium. If an ignited cannon-shot be placed in the middle of a large room, it radiates its heat to the ceiling, the walls, the floor, and the various objects around; they also radiate back again upon it; but, from its elevated temperature, it emits its heat faster than they, and therefore gives out more than it receives. Its temperature constantly descends, and continues to do so until it receives just as much as it gives, which takes place when it has reached the same degree as the objects around; for, other things being equal, bodies at the same temperature radiate with equal speed.

The process must, however, stop as soon as that equality of temperature is attained; for, if we suppose the shot to cool below that point, it would evidently begin to receive more heat from the objects around than it gave forth, and the excess accumulating in it, its temperature would at once rise.

When an equilibrium is obtained the process of radiation still continues, but the exchanges are equal. Two lighted candles placed together do not extinguish each other, or cease to exchange light with each other, nor do two bodies equally warm cease, for that reason, to exchange heat In a room, therefore, in which every thing has the same temperature, rays are continually exchanging, but each object maintains its own temperature, because it receives as much as it gives.

If a red-hot ball and a thermometer bulb are placed near one another, the bulb receives more heat from the ball than it gives to it, and its temperature therefore rises; but if a thermometer bulb and a snow-ball are placed in presence

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Do bodies at the same temperature still radiate? Describe the process of cooling of an incandescent body. When does the descent of temperature cease? When an equilibrium is obtained, what is the rate of exchanges? Describe the action in the case of a red-hot ball and a thermometer bulb.

of one another, the bulb, being the hotter body, gives more than it receives, and its temperature therefore descends. This is the explanation of the experiment with the conjugate mirrors. That experiment, as was observed, affords no proof that there are rays of cold: the effect is due to the fact that a mutual exchange is going forward between the two bodies, and the temperature of the hotter descends. The mirrors, of course, take no part in this phenomenon; their office is merely to direct the path of the rays, as has been explained.

On the principles of the radiation of heat is founded Wells's theory of the dew. After the sun goes down of an evening, drops of water condense on the leaves, grass, stones, and other objects exposed to the air. It was once a question whether this dew descended in the form of a light shower, or ascended from the ground. There are also certain circumstances apparently very mysterious attending its formation: the dew rarely falls on a cloudy night; it also apparently possesses a selecting power, depositing itself on some bodies in preference to others. The theory of Dr. Wells furnishes a beautiful explanation of these curious facts. During the day, the various bodies on the surface of the earth, receiving the rays of the sun, become warm; but at nightfall, when the sky is unclouded, they begin to cool; for, the process of radiation continuing without any source of supply their temperature must descend. While the sun shone they received as much heat from him as they gave forth to the sky, but when he sets the supply is cut off, and they therefore cool; and as there is always moisture in the air, their temperature descending, by-and-by the dew point is reached; they become cold enough to condense water from the surrounding air, and this is the dew. And as different bodies, according to the roughness or physical condition of their surfaces, radiate with different degrees of speed, as Leslie's canister proves, some of the objects exposed to the sky cool rapidly, and are covered with dew; but with others the dew point is never reached: hence the apparent selecting power. When there is a canopy of clouds over the sky, dew can not form, for the cloud radiates to the earth as much as the

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Describe the action of a snow-ball and a thermometer bulb. How is this connected with the experiment with conjugate mirrors? Under what circumstances does dew form? What is the theory of Wells? How does this explain the selecting power of bodies?

earth radiates to it: the exchanges are equal, and the equilibrium is maintained; but if the cloud disappears, the heat of the surface of the ground escapes away into the regions of space, and is lost; hence cloudy nights are warm, and a clear is often a frosty night.

For similar reasons, mountain tops are always colder than valleys. In a valley, the radiation is obstructed by the sides of the adjacent hills, but on the top of a mountain the free exposure to the sky permits of unchecked radiation.

It has already been observed, that conduction is only a form of radiation. In its ordinary acceptation, the term conduction implies passage from particle to particle, by reason of their being in contact; but we have proved that the constitution of matter involves the existence of interstices, and that heat can only pass from among these by radiating across the interstices; hence the term interstitial radiation.

An interesting conclusion may be drawn from the conditions of the passage of radiant heat through glass. We have seen it is necessary that the heat should come from a source of very high temperature to pass this medium with facility. Now the heat of the sun passes with the greatest freedom, as is well known when we stand before a window through which the sun shines. In the focus of a convex lens of glass exposed in the sun's rays, bodies may be readily set on fire. We infer, therefore, that the temperature of the sun is very high, a result which is corroborated by proofs drawn from other sciences.

LECTURE XVII.

OF LIGHT.—*Sources of Light.—The Sun.—Incandescence.—Combustion.—Different Colors of Lights.—Shadows.—Conditions of the Intensity of Light.—Photometers, Rumford's, Ritchie's, and the Extinction of Shadows.—Velocity of Light.—Law of Reflection. -Refraction.—Burning Glasses.*

THE phenomena of radiant heat lead us by imperceptible steps to the phenomena of light. In treating of the former,

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How does it explain the action of clouds? Why is it colder on mountains than in valleys? What is meant by interstitial radiation? What conclusion may be drawn as respects the temperature of the sun?

we have in many cases drawn illustrations from the latter; and, indeed, there are facts in relation to caloric which it is absolutely impossible to understand until we comprehend the analogous facts in light.

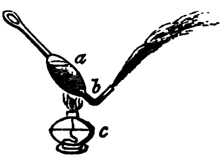
Light may be artificially produced by many different processes, such as the ignition of solids, combustion, and phosphorescence. Any solid, if sufficiently heated, becomes luminous; combustible gases take fire at a certain temperature in the air; and the diamond will emit a phosphorescent glow in a dark place, after it has been exposed to the day.

It is, however, to the sun that we are chiefly indebted. The quantity of light furnished by him infinitely exceeds that of all other natural and artificial sources, and its brilliancy is so great that the electric spark alone rivals it.

When the temperature of solid substances is raised to 1000° Fahrenheit, they begin to be luminous in the daylight, or, as it is termed, are visibly red-hot. It requires a far higher temperature to render a gas incandescent. This may be shown by holding a piece of thin platina wire in the current of hot air which rises from the apex of the flame of a lamp; the air is not visibly ignited, but the platina wire instantly becomes red-hot, showing the great difference in this respect between this metal and a gas.

Different vapors and gases evolve different quantities of light when ignited. The flame of burning hydrogen is scarcely visible in the daylight; that of alcohol is but little brighter; but, under the same circumstances, sulphuric ether emits much light. If we take a glass of the form *Fig.* 56, consisting of a bulb, *a*, and curved tube, *b*, and, having filled the bulb with ether, cause it to boil by the application of a lamp, *c*, the ether may be set on fire as it is forced out of the vessel by the pressure of its vapor. It burns in a beautiful arch of great brilliancy; but if we substitute alcohol for ether, the light becomes quite insignificant.

Fig. 56.



The light which is emitted by lamps and candles is, however, in reality, due to the disengagement of solid matter.

Mention some of the sources of light. At what temperature do solids become incandescent? In the combustion of vapors and gases, is there any difference in the amount of light emitted? How may this be illustrated? To what cause are we to attribute the light emitted by lamps and candles?

The constituents of the gas which produces the flame are carbon and hydrogen chiefly; of these, the latter is the more combustible, and is first burned; for a moment, therefore, the carbon exists in a solid form, in a state of extreme subdivision, and at a high temperature, but being in contact with the external air, it is immediately consumed.

Artificial lights differ in color. If alcohol be mixed with common salt and set on fire, the flame is of a yellow tint; if with boracic acid, it is green; if with nitrate of strontian it is red. It is upon these principles that the art of pyrotechny depends.

From whatever source light may come, it exhibits the same physical properties. It moves in straight lines. When it impinges on polished metallic surfaces, it is reflected; on dark surfaces, it is absorbed; on transparent surfaces, as glass, it is transmitted. In the last case, it is frequently forced into a new path, as we shall presently see, and then the phenomenon takes the name of refraction, because the ray is *broken* from its primitive course.

There are two different kinds of opacity, black and white; charcoal is a black opaque substance, earthen-ware is opaque white.

The shadows formed by opaque bodies arise from the interception of light in its rectilinear progress. They may be of two different kinds, the common and geometrical; the former arises from a luminous surface, the latter from a lucid point; the former consists of two portions, the *umbra* and *penumbra;* in the latter, the passage from total darkness to light on the side of the *shadow* is abrupt, and without the intervention of any *shade.*

The illuminating power of a light depends upon several conditions. As the distance increases it becomes less, the effect being inversely as the square of the distance; that is, at two feet it gives only one fourth of what it would do at one, at three feet only one ninth. The absolute intensity of the light also determines the result; thus, there are flames that are very brilliant, and others that are paler: the magnitude of the luminous surface is another of these conditions. The absorbent effect exerted on the passing rays by the air,

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How may artificial yellow, green, and red lights be made? In what course does light move? What is meant by the reflection, absorption, transmission, and refraction of light? How many kinds of opacity are there? What is the difference between common and geometrical shadows? What conditions determine the illuminating power of light?

or medium traversed, another; as is also the direct or oblique manner in which the rays are received on the illuminated surface.

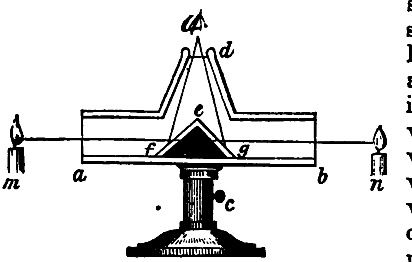
Of Photometers and the Measurement of Light.

The methods resorted to for the measurement of the intensity of light are very inferior to those for heat. They are not absolute, but comparative measures. Three are in common use: they are known as Rumford's method, Ritchie's method, and the method of extinction of shadows.

Rumford's method depends on the principle that of two lights, the most brilliant will cast the deepest shadow. If, therefore, the lights to be compared are made to cast shadows of the same opaque body, side by side, upon a piece of paper, the eye can, without difficulty, determine which of the shadows is darkest, and the light which casts it being moved to a greater distance, or the other being brought nearer, when the two shadows are of precisely the same depth, the distances of the lights from the paper will indicate their relative illuminating power; thus, if one is twice as far off as the other, its intensity is four times as great.

Ritchie's photometer depends on the equal illumination of surfaces. It consists of a box, *a b*, six or eight inches long, and one broad and deep, *Fig.* 57, in the middle of which a wedge of wood, *f e g*, is placed, with its angle, *e*, upward. This wedge is covered with white paper, neatly doubled to a sharp line at *e*. In the top of the box there is a conical tube, with an aperture, *d*, at its upper end, to which the eye is applied, and the whole may be raised to any suitable height by means of the stand, *c*. On looking down through *d*, having previously placed the two lights, *m n*, the intensity of which we desire to determine, on opposite sides of the box, they illuminate the paper surfaces exposed to them, and the eye sees both those surfaces at once. By

Fig. 57.



Describe Rumford's and Ritchie's photometric methods.

changing the position of the lights, we eventually make them illuminate the surfaces equally, and then, measuring their distances from *e*, their illuminating powers are as the squares of those distances.

In both this and the preceding method, a difficulty arises when the lights to be compared are of different tints. To some extent, this may be avoided by placing in Ritchie's instrument a colored glass at *d*.

The third method, that of extinction of shadows, is much more exact, differences in the color of the lights even serving to give greater accuracy. It depends on the following principle. If a light is made to throw the shadow of an opaque object upon a white screen, there is a certain distance at which, if a second light be brought, its rays, illuminating the screen, will totally obliterate all traces of the shadow. It has been found that eyes of average sensitiveness fail to distinguish the effect of a light when it is in presence of another sixty-four times as intense. The precise number varies with different eyes, but to the same eye it is always the same. If there be any doubt as to the perfect disappearance of the shadow, the receiving screen may be agitated or moved a little. This brings the shadow, to a certain extent, into view again. Its place can then be traced, and on ceasing the motion the disappearance verified.

When, therefore, we desire to measure the relative intensities of lights, we have only to determine at what distance they will extinguish a given shadow. Their intensities are as the squares of those distances. This is the method by which I determined the amount of light given off by ignited solids at various temperatures, as will be hereafter mentioned.

Light does not move from point to point instantaneously, but at a rate which is measurable. From certain astronomical facts, it appears that the velocity is about 192,000 miles per second.

When a ray falls upon a polished surface it suffers reflexion, and when it falls upon a transparent medium it undergoes refraction.

It is in consequence of this that convex lenses converge the rays of the sun, and so produce a high temperature. In

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What difficulty is encountered in these methods? On what principle does the method by extinction of shadows depend? Describe the process. At what rate does light move?

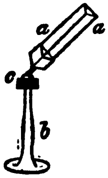
Fig. 58.

this application they are called burning glasses, and, until the invention of the Voltaic pile and oxyhydrogen blowpipe, presented the most energetic means for elevation of temperature. If made of thin and pure glass, and of a diameter of from one to three feet, these lenses will effect the instantaneous fusion of most earthy and metallic bodies. Even the most fixed metals volatilize at the focal point.

LECTURE XVIII.

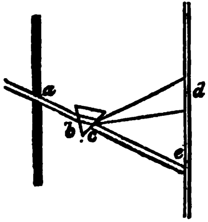
THE CONSTITUTION OF SOLAR LIGHT.—*Newton's Discoveries.—The Solar Spectrum.—Order of the Intensity of Light.—Distribution of Heat.—The Chemical Effects.—Distribution of Chemical Power.—Fixed Lines.*

Fig. 59.



SIR ISAAC NEWTON first succeeded in proving the compound nature of light by the aid of a very simple instrument, a glass prism. It consists of a piece of glass having three sides, *Fig.* 59, *a a*, and is usually mounted on a brass stand, *b*, with a ball and socket joint, *c*, which allows us to place it in any required position.

Fig. 60.



Let the shutters of a room be closed, and through an aperture in one of them, suitably situated, let a beam of the sun enter, *Fig.* 60, *a*. It pursues, of course, a straight path, following the dotted line, *a e*. Now let the prism interpose in the position, *b c*, so as to intercept completely the ray. This goes no longer to *e*, but is bent out of its course, and moves in the direction *d*.

Two striking facts are now to be re-

What are burning glasses? Describe the prism. State the effect which ensues when a ray passes through the prism.

marked: first, the ray *a* is refracted or broken from its path; and, second, instead of forming on the surface *d*, upon which it falls, a white spot, an elongated and beautifully-colored image is produced. These colors are seven in number: red, orange, yellow, green, blue, indigo, violet. The separation of these colors from one another is designated by the term Dispersion.

Newton has shown that white light consists of these various-colored rays blended together; and their separation in the case before us is due to the fact that the prism refracts them unequally. On examining the position of the colors, in their relation to the point *e*, to which they would all have gone had not the prism intervened, it is ascertained that the red is least disturbed or refracted from its original path, and the violet most; for these reasons, we call the red the least refrangible ray, the violet the most refrangible, and the yellow intermediately.

That the mixture of these colored rays reproduces white light, may be proved by resorting to any optical contrivance which will reassemble them all in one point; that point will be perfectly white.

Let *v r*, *Fig.* 61, represent the spectrum which is given by a sunbeam after its passage through a prism, and *e* the point to which it would have gone had not the prism intervened; the order of the colors commencing with that which is least disturbed from its path, or nearest to *e*, is as follows:

Red,
Orange,
Yellow,
Green,
Blue,
Indigo,
Violet.

Fig. 61.

These colors gradually blend into each other, so that their boundaries can not be traced; and instead of a circular spot, which would have resulted had they gone forward to *e*, they are dilated out, so as to form an elongated figure with parallel sides; at the two extremities the light fades gradually away, so that we can not trace its limit with precision.

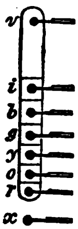
What is meant by refraction? What by dispersion? What is Newton's theory of the constitution of light? Which is the least, and which the most refrangible ray? Of what does white light consist? What is the order of refrangibility of colors? What is the figure of the spectrum?

Besides this difference of color, the light differs in intrinsic brilliancy in the different spaces. Thus, if we receive the spectrum on a piece of finely-printed paper, we can read the letters in each color at very different distances. In the yellow region the light is most brilliant, and there we can read farthest. From this point the light declines in brilliancy to the two ends of the spectrum, its intensity in the colored spaces being in the following order:

Yellow,
Green,
Orange,
Red,
Blue,
Indigo,
Violet.

Sir W. Herschel discovered, while using large reflecting telescopes, that the calorific rays of the sun pass with different degrees of facility through colored glasses, and was led to examine the temperature of the colored spaces of the solar spectrum, to see whether the intensity of the heat follows the intensity of the light. It was reasonable to suppose that the yellow space, being the brightest, would be also the hottest. He therefore placed delicate thermometers in the various colored spaces, and kept them in these spaces until they had risen as high as the ray could bring them. The thermometer *v*, *Fig.* 62, had risen the least, and in succession, *i*, *b*, *g*, *y*, *o*, *r*; that which was immersed in the red being the highest.

Fig. 62.



It thus appears that the distribution of heat in the colored spaces of the solar spectrum is not the same as the distribution of light; that the yellow ray, though it is the most luminous, is far from being the hottest, and that the intensity of the heat steadily increases from the violet to the red extremity.

But this is not all: he farther found, that if a thermometer be brought out of the red region in the position *x*, beyond the limits of the spectrum, and where there is no light whatever, it stands higher than any of the others. From this a most important conclusion may be drawn, that the light and heat existing in the sunbeam are distinct and in-

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How may the illuminating power be determined? What is the order of illuminating power? Describe the discovery of Sir W. Herschel. Is the distribution of heat in the spectrum the same as the distribution of light? What fact indicates that the light and heat are separate and independent agents?

dependent agents, and that by such processes as we are considering they may be perfectly separated from each other.

It was discovered by some of the alchemists, centuries ago, that the chloride of silver, a substance of snowy whiteness, turns black on exposure to the light. More recently, a great number of such bodies have been found—bodies which change, with greater or less rapidity, under the influence of this agent. The iodide of silver, which forms the basis of the process known as the Daguerreotype, is such; and a mixture of chlorine and hydrogen gases in equal volumes, though it may be kept unchanged for a great length of time in the dark, explodes violently on exposure to the sunshine. In the same manner, changes take place in a great variety of organic compounds; the most delicate vegetable hues are soon bleached, and, indeed, a ray of light can scarcely fall on a surface of any kind without leaving traces of its action.

If a piece of paper, spread over with chloride of silver, be placed in the solar spectrum, it soon begins to blacken. But it does not blacken with equal promptitude in each of the colored spaces; the effect takes place most rapidly among the more refrangible colors, and especially in the violet region. As in the case of heat, the effect extends far beyond the limit of the spectrum, and where the eye can not discover a trace of light. We may be led, therefore, to conclude that there exists in the sunbeam an agent capable of producing chemical effects, which exerts no action on a thermometer, which can not be perceived by the eye, and which, therefore, is neither heat nor light.

By placing mixtures of chlorine and hydrogen in small vials, and immersing them in the colored spaces, we can readily determine the place of maximum action, and the distribution of the chemical influence throughout the spectrum. In this, as in the former instance, the greatest effect is found among the more refrangible colors, and from that point diminishes toward each extremity of the spectrum.

Fig. 63.

What changes does chloride of silver undergo in the sunshine? When a mixture of chlorine and hydrogen is exposed to the sun, what occurs? How does light change vegetable colors? Which ray darkens the chloride of silver most? What proof have we that another agent exists in the sun's rays besides light and heat? What ray affects the mixture of chlorine and hydrogen most powerfully?

When the aperture which admits a ray of light into the dark room, *Fig*. 60, is a narrow fissure or slit, not more than the one thirtieth of an inch in width, the spectrum which is formed by the action of a prism is crossed by great numbers of black lines. These always are found in the same position, as respects the colored spaces, and, from the invariability of that position, are much used as boundary marks. They are designated by the letters of the alphabet, and their relative magnitude, with their position, is given in *Fig*. 63, on the previous page.

LECTURE XIX.

WAVE THEORY OF LIGHT.—*Proofs of the Existence of the Ether.—Light consists of Waves in it.—The Ethereal Particles move but little.—Distinction between Vibration and Undulation.—Fresnel's Theory of Transverse Vibrations.—Transverse and Normal Waves.—Brilliancy of Light depends on Amplitude of Vibration.*

THE cause of light is an undulatory movement taking place in the ethereal medium. That such a medium exists throughout all space, seems to be proved by a number of astronomical facts. It exerts a resisting agency on bodies moving in it. From its tenuity, we should scarcely expect that it would impress any disturbance on the great planetary masses; but on light, gaseous cometary bodies, it produces a perceptible action. The comet of Encke, with a period of about 1200 days, is accelerated in each revolution by about two days; and that of Biela, with a period of 2460 days, is accelerated by about one day. As there is no other obvious cause for these results, astronomers have very generally looked upon them as corroborative proofs of the existence of a resisting medium, that universal ether to which so many other facts point.

In this elastic medium, undulatory movements can be propagated in the same manner as waves of sound in the air. It is to be clearly understood that the ether and light are distinct things; the latter is merely the effect of move-

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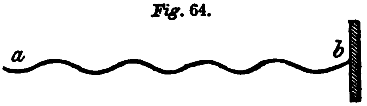
What are the fixed lines? How are these lines designated, and what is their use? What proofs have we of the existence of an ethereal medium? What is the relation between the ether and light?

ments in the former. Atmospheric air is one thing, and the sound which traverses it another. The air is not made up of the notes of the gamut, nor is the ether composed of the seven colors of light.

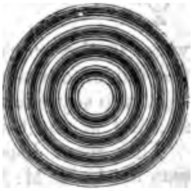
Across the ether, undulatory movements, resembling, in many respects, the waves of sound in the atmosphere, traverse with prodigious velocity. From the eclipses of Jupiter's satellites, and other astronomical phenomena, it appears that the rate of the propagation of light, or the velocity with which these waves advance, is 192,000 miles in a second. We are not, however, to understand by this that the ethereal particles rush forward in a rectilinear course at that rate: those particles, far from advancing, remain stationary.

Fig. 64.



If we take a long cord, *a b*, *Fig.* 64, and having fastened it by the extremity, *b*, to a fixed obstacle, commence agitating the end, *a*, up and down, the cord will be thrown into wave-like motions, passing rapidly from one end to the other. This may afford us a rude idea of the nature of the ethereal movements. The particles of which the cord is composed do not advance or retreat, though the undulations are rapidly passing.

Fig. 65.



So, too, if in the centre, *c*, of a surface of water, *Fig.* 65, we make a tapping motion with the finger, circular waves are propagated, which, expanding as they go, soon reach the sides of the vessel which holds the water. A light object placed on the surface is not violently drifted forward by the waves, but remains entirely motionless. We see, therefore, that there is a wide distinction between the motion of a wave and the motions of the particles among which it is passing. They retain their places, but the wave flows rapidly forward.

A distinction is to be made between the words vibration and undulation. In the case of the cord, *Fig.* 64, the vi-

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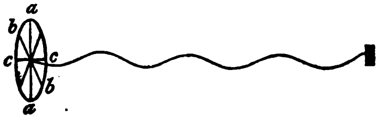
At what rate is light propagated? Do the ethereal particles move forward at that rate? How may the movements of ethereal waves be represented by a cord? How may they be represented on the surface of water? Do the vibrating particles move forward with the wave?

bration is represented by the movement exerted by the hand at the free extremity, *a;* the undulation is the wave-like motion that passes along the cord. In the case of the water, *Fig.* 65, the vibration was represented by the tapping motion of the finger, the undulation by the resulting wave. We therefore see that these stand in the relation of cause and effect: the vibration is the cause, and the undulation the effect. Throughout the ethereal medium, each particle vibrates and transmits the undulatory effect to the particles next beyond it.

In the same way as a vibrating cord agitates the surrounding air, and makes waves of sound pass through it, so does an incandescent or shining particle, vibrating with prodigious rapidity, impress a wave-like movement on the ether, and the movement eventually impinging on the eye is what we call light.

To refer again to the simple illustration given in *Fig.* 64: it is obvious that there are an infinite variety of directions in which we may vibrate that cord or throw it into undulations. We may move it up and down, or horizontally right and left, and also in an infinite number of intermediate directions, every one of which is transverse, or at right angles to the length of the cord, as *a a*, *b b*, *c c*, &c., *Fig.* 66. This is the peculiarity of the movement of light. Its vibrations are transverse to the course of the ray; and in this it differs from the movement of sound, in which the vibrations are normal, that is to say, executed in the direction of the resulting wave, and not at right angles to it.

Fig. 66.



This great discovery of the transverse vibrations of light was made by M. Fresnel. It is the foundation of the whole theory of optics, and offers a simple but brilliant explanation of so many of the phenomena of light, that the undulatory theory is by many writers designated the THEORY OF TRANSVERSE VIBRATIONS.

It may, however, be remarked, that though light consists

What is the distinction between vibrations and undulations? How does each ethereal particle propagate the wave to those beyond it? Is there any analogy between sound and light? In how many ways may a cord be vibrated? What is implied by the term theory of transverse vibrations?

of rays originating in these transverse motions, it is not impossible that there may be other phenomena which correspond to movements in other directions. To those movements our eyes are totally blind, and hence we can not speak of them as light. In the same way there may be motions in the air, due to transverse vibrations, but to them our ear is perfectly deaf. But it is not improbable that God has formed organs of vision and organs of hearing in the case of other animals upon a different type; eyes that can perceive normal vibrations in the ether, and ears that can distinguish transverse sounds in the air.

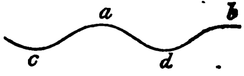
Lights differ from each other in two striking particulars —brilliancy and color. These are determined by certain affections or qualities in the waves. On the surface of water we may have a wave not an inch in altitude, or a wave, as the phrase is, "mountains high." Under these circumstances, waves are said to differ in amplitude; and, transferring this illustration to the case of light, a wave, the amplitude of which is great, impresses us with a sense of intensity or brilliancy, but a wave, the amplitude of which is little, is less bright. The brilliancy of light depends on the magnitude of the excursions of the vibrating particles.

LECTURE XX.

WAVE THEORY OF LIGHT.—*Colors of Light depend upon Wave Lengths.—Interference of Sounds.—Young's Theory of Interference of Light.—Condition of Interference.—Explanation of Lights and Shades in Shadows.*

BY the length of a wave upon water, we mean the distance that intervenes from the crest of one wave to that of the next, or from depression to depression. Thus, in *Fig.* 67, from *a* to *b*, or, what is the same, from *c* to *d*, constitutes the wave length.

Fig. 67.



In the ether the length of the waves determines the phe-

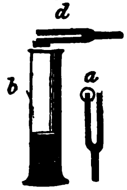
Are other motions possible? What is meant by the amplitude of waves? On what does the brilliancy of light depend? What is meant by the length of a wave?

nomenon of color; this may be rigorously proved, as we shall soon see, when we come to the methods by which philosophers have determined the absolute lengths of undulations. It has been found that the longer waves give rise to red light, the shorter ones to violet, and those of intermediate magnitudes the other colors in the order of their refrangibility.

Two rays of light, no matter how brilliant they are separately, may be brought under such relations to one another as to destroy each other's effect and produce darkness. Light added to light may produce darkness. Two sounds may bear such a relation to each other that they shall produce silence; and two waves, on the surface of water, may so interfere with one another that the water shall retain its horizontal position.

Take two tuning forks of the same note, and fasten by a little sealing wax on one prong of each a disc of card-board, half an inch in diameter, as seen *Fig.* 68, *a*. Make one of the forks a little heavier than the other, by putting on the end of it a drop of the wax.

Fig. 68.



Then take a glass jar, *b*, about two inches in diameter and eight or ten long, and having made one of the forks vibrate, hold it over the mouth of the jar, as seen at *d*, its piece of card-board being downward; commence pouring water into the jar, and the sound will be greatly re-enforced. It is the column of air in the jar vibrating in unison with the fork, and we adjust its length by pouring in the water; when the sound is loudest, we cease to pour in any more water, the jar is adjusted, and we can now prove that two sounds added together may produce silence.

It matters not which fork is taken, whether it be the light or the loaded, on making it vibrate and holding it over the mouth of the resonant jar, we hear a uniform and clear sound, without any pause, stop, or cessation. But if we make both vibrate over the jar together, a remarkable phenomenon arises, a series of sounds alternating with a series of silences; for a moment the sound increases, then dies

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What is the connection between color and wave-length? What is meant by the interference of lights or of sounds? Give an illustration of the interference of sounds. What is the character of the sound which the resonant jar emits?

away and ceases, then swells forth again, and again declines, and so it continues until the forks cease vibrating. The length of these pauses may be varied by putting more or less wax on the loaded fork; and as we can see that even during the periods of silence both forks are rapidly vibrating, the experiment proves that two sounds taken together may produce silence.

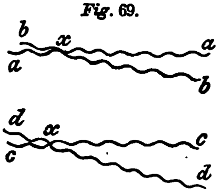
Under these circumstances, waves of sound are said to interfere with each other, and in like manner interference takes place among the waves of light. We can gather an idea of the mechanism by considering this case in waves upon water, in which, if two undulations encounter under such circumstances that the concavity of the one corresponds with the convexity of the other, they mutually destroy each other's effect.

If two systems of waves of the same length encounter each other after having come through paths of *equal* length, they will not interfere. Nor will they interfere even though there be a difference in the length of these paths, provided that difference be equal to one whole wave, or two, or three, &c.

But if two systems of waves of equal length encounter each other after having come through paths of *unequal* length, they will interfere, and that interference will be complete when the difference of the paths through which they have come is half a wave, or 1½, 2½, 3½, &c.

These cases are respectively shown at *a b*, and *c d*, *Fig.* 69, at the point of encounter, *x*; in the first instance, the two sets of waves are in the same phase, that is, their concavities and convexities respectively correspond, and there is no interference; but in the second case, at the point of encounter, *x*, the two systems are in opposite phases, the convexity of the one corresponding with the concavity of the other, and interference takes place.

Fig. 69.



Upon these principles, we can account for the remarkable results of the following experiment: From a lucid point,

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Why are there pauses in it? At the time of these pauses, are the forks vibrating? When two waves upon water encounter each other, under what circumstances will they interfere? When systems of waves of equal length encounter one another, when do they, and when do they not, interfere?

Fig. 70.

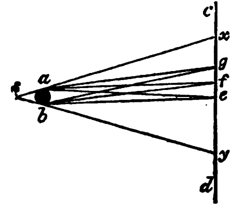

Fig. 71.

s, *Fig*. 70, which may be formed by the rays of the sun converged by a double convex lens of short focus, or by passing a sunbeam through a pinhole, let rays emanate, and in them place the opaque obstacle, *a b*, which we will suppose to be a cylindrical body, seen endwise in the figure; at some distance beyond place a screen of white paper, *c d*, to receive the shadow. It might be supposed that this shadow should be of a magnitude included between *x y*, because the rays, *s a*, *s b*, which pass the sides of the obstacle, impinge on the paper at those points. It might farther be supposed, that within the space *x y* the shadow should be uniformly dusky or dark; but, on examining it, such will not be found to be the case. The shadow will be found to consist of a series of light and dark stripes, as represented in *Fig*. 71. In its middle, at *e*, *Figs*. 70 and 71, there is a white stripe; this is succeeded on each side by a dark one; this, again, by a bright one, and so on alternately.

Upon the undulatory theory, all this is readily explained. Sounds easily double round a corner, and are heard though an obstacle intervenes. Waves upon water pass round to the back of an object on which they impinge, and the undulations of light in the same manner flow round at the back of the piece of wire, *a b*, *Fig*. 70; and now it is plain that two series of waves which have passed from the sides of the obstacle to the middle of its shadow, that is, along the lines *a e*, *b e*, have gone through paths of equal length, and, therefore, when they encounter at the point *e*, they will not interfere, but exalt each other's effect.

But, leaving this central point, *e*, and passing to *f*, it is plain that the systems of waves which have come through the paths *a f*, *b f*, have come through different distances, for *b f* is longer than *a f;* and if this difference be equal to the length of half a wave, they will, when they encounter at the point *f*, interfere and destroy each other, and a dark stripe results.

Describe the experiment represented in *Fig*. 70. Is the resulting shadow uniformly dark? At the central point of the shadow, is it dark or light? Explain the cause of this central light space, and of the alternate dark and light ones on each side of it.

Beyond this, at the point *g*, the waves from each side of the obstacles, *a g*, *b g*, again have come through unequal paths; but, if the difference is equal to the length of one whole wave, they will not interfere, and a white stripe results.

Reasoning in this manner, we can see that the interior of such a shadow consists of illuminated and dark spaces alternately: illuminated spaces, when the light has come through paths that are equal, or that differ from each other by 1, 2, 3, 4, . . &c., waves; and dark, when the difference between them is equal to ½, 1½, 2½, 3½, . . &c., waves.

That it is the interference of the light coming from the opposite sides of the opaque object which is the cause of these phenomena, is proved by the circumstance that if we place an opaque screen on one side of the obstacle, so as to prevent the light passing, the fringes all disappear.

LECTURE XXI.

WAVE THEORY OF LIGHT.—*Measurement of the Length of a Wave of Light.—Length differs for different Colors.—Measurement of the Period of Vibrations.—Nature of Polarized Light.—Plane, Circular, and Elliptical Polarized Light.—Reflection, Refraction, and Absorption of Light.*

THE experiment, *Fig.* 70, may enable us to determine the length of a wave of light. This may be readily done by measuring the distances *a f* and *b f*, or from the sides of the obstacle to the first bright stripe from the central one, for at that point the difference between those two lines, *a f* and *b f*, is equal to the length of one wave. We might employ the second bright stripe; the difference then would be equal to two waves.

Farther, if, instead of using ordinary white light, radiating from the lucid point, *s*, we use colored lights, such as red, yellow, blue, &c., in succession, we shall find that the

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What is the length of the paths of the waves which go to the illuminated spaces, and of those which go to the dark ones? How can it be proved that the waves from the opposite sides of the obstacle interfere? How, by thi arrangement, might we measure the length of a wave of light?

wave length determined by the process just explained differs in each case; that it is greatest in red, and smallest in violet light. By exact experiments made upon methods more complicated than the elementary one here given, it has been found that the different colored rays of light have waves of the following length:

Wave Lengths of the Different Colors of Light.

The English inch is supposed to be divided into ten millions of equal parts and of those parts the wave lengths are:

For red light	256	For blue	196
" orange	240	" indigo	185
" yellow	227	" violet	174
" green	211		

In this manner, it is proved that the different colors of light arise in the ether from its being thrown into waves of different lengths.

Knowing the rate at which light is propagated in a second, and the wave length for a particular color, we can readily tell the number of vibrations executed in a second, for they plainly are obtained by dividing 192,000 miles, the rate of propagation, by the wave length. From this it appears, that if a single second of time be divided into one million of equal parts, a wave of red light trembles or pulsates 458 millions of times in that inconceivably short interval, and a wave of violet light 727 millions of times.

In speaking of the constitution of matter in Lectures I. and II., I had occasion to allude to the amazingly minute scale on which it is constructed. The remarkable facts we are now considering are a monument to the genius of Newton and his successors, for they give us a just idea of the scale of space and time upon which Nature carries on her works among the molecules of matter.

Common light, as has been said, originates in vibratory motions taking place in every direction transverse to the ray. With polarized light it is different; to gather an idea of the nature of polarized light, we must refer once more to the cord, *Fig.* 66, which, as has been said, serves to imitate common light when its extremity is vibrated vertically, hor-

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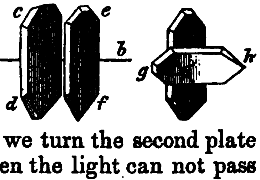
When different colors of light are used, are the waves found to be of equal length? What is the length of a wave of red and of violet light respectively? How can we ascertain the number of vibrations in a second? On the undulatory theory, in what direction do the ethereal particles vibrate in the case of common light? What is the case in polarized light?

izontally, and in all intermediate positions in rapid succession. But if we simply vibrate it up and down, or right and left, then it imitates polarized light; polarized light is, therefore, caused by vibrations transverse to the ray, but which are executed in one direction only.

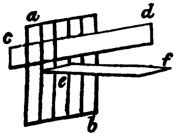
There is a certain gem, the tourmaline, which serves to exhibit the properties of polarized light. If we take a thin plate of this substance, *c d*, properly cut and polished, and allow a ray of light, *a b*, *Fig.* 72, to fall upon it, that ray will be freely transmitted through a second plate if it be held symmetrically to the first, as shown at *e f;* but if we turn the second plate a quarter round, as seen at *g h*, then the light can not pass through. The rays of the meridian sun can not pass througb a pair of crossed tourmalines.

Fig. 72.



The cause of this is obvious: if we take a thin lath or strip of pasteboard, *c d*, *Fig.* 73, and hold it before a cage, or grate, *a b*, it will readily slip through when its plane coincides with the bars; but if we turn it a quarter round, as at *e f*, then of course it can not pass the bars.

Fig. 73.



Now the plate of tourmaline, *Fig.* 72, *c d*, polarizes the light, *a b*, which falls upon it, that is, the waves that pass through it are vibrating all in one plane. They pass, therefore, readily through a second plate of the same kind, so long as it is held in such a way that its structure coincides with that motion, but if it be turned round so as to cross the waves, then they are unable to pass through it.

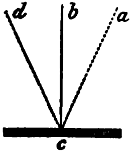
There are many ways in which light can be polarized: by reflection, refraction, double refraction, &c. The resulting motion impressed on the ether is the same in all cases.

Light modified as just described is designated plane polarized light; but there are other varieties of polarization. If the end of the rope, *Fig.* 66, be moved in a circle, circular waves will be produced, imitating circularly polarized light; and if it be moved in an ellipse, elliptical polarized light.

Describe the optical properties of the tourmaline. Give an illustration of the phenomenon. What is the cause of the action of the second tourmaline plate? Mention some of the methods by which light may be polarized. What is circularly polarized light? What is elliptically polarized light?

The undulatory theory of light gives a clear account of the ordinary phenomena of optics. The general law under which light is reflected from polished surfaces is a direct consequence of it; that law is: that the angle, *d c b*, *Fig.* 74, made by the reflected ray, *d c*, with a perpendicular, *c b*, drawn to the point *c*, at which the light impinges, is equal to the angle, *a c b*, which the incident ray makes with the same perpendicular, or, as it is briefly expressed, "the angles of incidence and reflection are equal to each other, and on opposite sides of the perpendicular."

Fig. 74.



By the aid of this law, we can show the action of reflecting surfaces of any kind, and discover the properties of plane and curved mirrors, whether they be concave or convex, spherical, elliptical, paraboloidal, or any other figures.

From the undulatory theory, the law of the refraction of light also follows as a necessary consequence. It is: "in every transparent substance, the sines of the angles of incidence and refraction are to each other in a constant ratio;" and by the aid of this law we can determine the action of media bounded by surfaces of any kind, plane or spherical, concave or convex. It explains the action of lenses, and the construction of refracting telescopes and microscopes.

Sir Isaac Newton's discovery, that white light arises from the mixture of the different colored rays in certain proportions, explains the cause of the colors which transparent media often exhibit; thus, if glass be stained with the oxide of cobalt, it allows a blue light to pass it, and upon such principles the art of painting on glass depends; different colors being communicated by different metallic oxides. The cause of this effect is readily discovered; for, if we make the light which enters a dark room, as in *Fig.* 60, pass through such a piece of stained glass before it goes through the prism, and examine the resulting spectrum, we find that several rays are wanting in it; that the glass has absorbed or detained some, and allowed others to traverse it. A piece of blue glass thus suffers most of the blue light to pass, but stops the green, the yellow, &c. But it is also to be observed, that the light which is transmitted by any of

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What is the general law of reflection? What is the law of the refraction of light? What is the cause of the colors of transparent media? Is the light transmitted through these colored media pure?

these colored media is not pure, it is contaminated with other tints; the blue glass, for instance, does not stop all the rays except the blue; it allows a large portion of the red to pass, and hence the light it transmits is more or less compound.

LECTURE XXII

PRODUCTION OF LIGHT. — *By Incandescence.* — *Point at which Bodies are Red Hot.* — *All Solids shine at the same Degree.* — *Colors Emitted.* — *Rate of Brilliancy.* — *Nature of Flames.* — *Phosphorescence.* — *Controlled by Temperature.*

A THEORETICAL explanation of the chemical action of light must depend on the views entertained of the nature of that agent. In a series of memoirs, published in the London and Edinburgh Philosophical Magazine between the years 1847 and 1851, I have investigated the circumstances under which light arises by artificial processes, and shall here proceed to detail the chief results.

There are three general processes by which light is obtained artificially: 1st. By the ignition of bodies; 2d. By their combustion or burning; 3d. By phosphorescence.

1st. *Of the Production of Light by Ignition.*—All solid substances shine when their temperature is raised to a certain degree. The point at which this occurs has been variously estimated. Sir Isaac Newton places it at 635°; Davy, at 812°; Wedgewood, at 947°; Daniell, at 980° By taking advantage of the improved means which the present state of science offers, I found that for platinum it is 977°, or, if Laplace's coefficient of dilatation be used in the calculation, 1006°.

By inclosing a number of different substances with a mass of platinum in a gun-barrel, the temperature of which was gradually raised, it was found, on looking down the barrel, that they all commenced to shine at the same moment, and this even though, as in the case of lead, the melted condition had been assumed. I therefore infer that all solids and liquids begin to shine at the same degree of the thermometer.

What is the temperature of ignition? Do all substances shine at the same degree?

The color of the light which the ignited substance emits depends upon the degree of heat to which it is exposed. Making due allowance for the physiological imperfections of the eye, there can be no doubt that the first rays which appear are the red, and as the temperature is made gradually to go up, the yellow, orange, green, blue, indigo, and violet are emitted in succession. At 2130° all these colors are exhibited, and from their commixture the substance appears *white hot.*

It may therefore be inferred, that as the temperature of an incandescent body rises, it emits rays of light of an increasing refrangibility.

By the aid of the method of extinction of shadows it was proved, that as the temperature of an ignited solid rises, the intensity of the light increases very rapidly. For example, platinum at 2600° emits almost forty times as much light as it does at 1900°, as the following table shows:

Intensity of Light emitted by Platinum at different Temperatures.

Temperature of the Platinum.	Intensity of its Light.
980° . . .	0·00
1900 . . .	0·34
2015 . . .	0·62
2130 . . .	1·73
2245 . . .	2·92
2360 . . .	4·40
2475 . . .	7·24
2590 . . .	12·34

From a parallel series of experiments, in which the heat radiated by the ignited platinum was measured, a striking analogy between the two agents appears. Thus, if the quantity of heat radiated by platinum at 980° be taken as unity, it will have increased at 1440° to 2·5; at 1900° to 7·8; at 2360° to 17·8 nearly. The rate of increase is, therefore, very rapid, as in the preceding case.

2d. *Of the Production of Light by Combustion.*—It has been long known that all common flames are incandescent shells, the interior of which is dark, and it has been supposed that there are certain flames which emit particular rays only, but an examination by the prism showed that in every flame every prismatic color is found. The red which

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What is the order in which the colored rays are emitted? At what rate does the brilliancy of the light increase? Does the same hold good for the radiant heat? What is the condition of the interior of a flame?

burning cyanogen, and the blue which burning sulphur emits, are compound colors.

By burning solid carbon in oxygen gas, it appeared that there is a connection between the refrangibility of the light which a burning body yields and the intensity of the chemical action going on, and that the refrangibility always increases as the chemical action increases.

From this it appears that flames, such as those of lamps and candles, consist of a series of concentric and differently colored shells, the most interior one being red, and having a temperature of 977°. Upon this, in succession, are placed orange, yellow, green, blue, indigo, and violet shells. The flame, looked at directly, appears to yield white light, because of the commixture of these rays; but, on being submitted to the action of a prism, they are separated from each other, and their individual existence proved. If, therefore, we could isolate a horizontal section of such a flame, it would have the aspect of an iris or rainbow ring.

Upon the principle that, the more energetic the chemical action, the higher the refrangibility of the light emitted, we may explain, without difficulty, the colors which different flames present. The red tints predominate in the flame of burning cyanogen, because in that gas there is an element wholly incombustible—the nitrogen. This, as it is set free, cuts off the free access of the air, and the burning goes on tardily—very much in the same manner as in an oil lamp to which the air is imperfectly supplied. On the other hand, carbonic oxide burns blue, because of the small quantity of air required to carry it to its maximum of oxydation. The color of flames depends, therefore, on the completeness or incompleteness of the combustion; this principle readily accounting for those cases in which means are used for retarding or promoting the rate of burning, as where an atmosphere of oxygen is used, or air introduced into the interior of a flame by means of a blowpipe, the bright blue cone arising in this latter instance being a striking indication of the increased rapidity of combustion.

There is, therefore, a direct connection between the vehemence with which chemical affinity is satisfied and the refrangibility of the resulting light. If, as there are many reasons for supposing, all chemical changes are attended by

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What is the structure of a flame? Explain the cause of the colors of flames. Why is the blowpipe cone blue?

vibratory movements of the particles of the bodies engaged it might well be anticipated that these vibrations should increase in frequency as the action becomes more violent. But it is to be remembered that an increased frequency of vibration is the same thing as an increased refrangibility.

3d. *Of the Production of Light by Phosphorescence.*—All solid substances, except the metals, possess the property of shining after they have been exposed to the sun. In some, the effect lasts but for a moment; in others, it is of longer duration and considerable splendor. Among the best phosphori may be mentioned the sulphuret of barium, the sulphuret of calcium, certain varieties of fluor spar, and of diamond. Phosphorescence has generally been regarded as unattended by the emission of heat.

By suitable experimental arrangements, I ascertained that the best phosphori, when at their maximum of glow, do not increase in volume by so much as the $\frac{1}{12000}$ part; but that there is minute expansion can not be doubted, since, when means sufficiently delicate are resorted to, a feeble rise of temperature can be detected. The intensity of the light disengaged is to some extent deceptive; for, by resorting to the method of the extinction of shadows, it was shown that a fine specimen of chlorophane, at its maximum of brightness, yielded a light three thousand times less intense than the flame of a very small oil lamp.

The quantity of light a substance can receive when exposed to the sun depends upon the temperature. The colder the phosphorus is, the more brightly will it subsequently shine. If kept hot during its exposure, it will not shine at all. If a diamond placed upon ice is submitted to the sun, and then brought into a dark room, the temperature of which is 60°, for a time there is a glow, but presently the light declines and dies out. Let the diamond now be put in water at 100°; again it shines, and again its light dies away. If it next be removed from that water and suffered to cool and then be reimmersed, it will not shine again; but if the water be heated to 200°, and the diamond be dropped into it, again it glows, and again its light dies away. There is, therefore, a correspondence between the light disengaged and the temperature applied.

What is the connection between chemical affinity and refrangibility? What substances exhibit phosphorescence? Do phosphorescent bodies expand? What is the actual intensity of the light of phosphori? How is phosphorescence controlled by temperature?

The phenomena of phosphorescence may all be explained on the principles of the theory of undulations; for from a shining body undulations are propagated in the ether, and these, impinging on a phosphorescent surface, throw its molecules into a vibratory movement. These, in their turn, impress on the ether undulations; but, by reason of the difference of its density, compared with that of the molecules, they do not lose their motion at once, but it continues for a time gradually declining away, and ceasing when the *vis viva* of the molecules is exhausted.

We may therefore abandon expressions derived from the material theory of light, such as the *absorption* and subsequent *emission* of the luminous agent, and conclude that, whenever a radiation falls upon a surface of any kind, it throws the particles thereof into a state of vibration, as when a stretched string is made to vibrate in sympathy with a distant musical sound. This view includes at once all the facts of the radiation of heat and the theory of calorific exchanges; it also offers an explanation of the connection of the atomic weights of bodies and their specific heats. It suggests that all cases of the decomposition of compound molecules, under the influence of light, is owing to a want of consentaneousness in the vibrations of the impinging ray and those of the molecular group, which, unable to maintain itself, is broken down, under the periodic impulses it is receiving, into other groups, which can vibrate along with the ray

LECTURE XXIII.

CHEMICAL ACTION OF LIGHT.—*Action of Natural and Artificial Lights.—Preliminary Absorption.—Change in the Ray.—Necessity of Absorption.—The Daguerreotype.—Explanation of the Process.—Its Imperfections—Other Processes.*

WHEN a solar spectrum falls upon paper covered over with chloride of silver, the chloride turns black in the more refrangible regions. The darkening effect of light was known to the alchemists. The bleaching action on vegetable colors must have been observed from the earliest times,

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On what principles may phosphorescence be explained?

but it is only recently that the phenomenon has been more particularly investigated.

From whatever source it may be derived, light exerts chemical action. The moonbeams are sufficiently intense to give copies of that satellite on sensitive surfaces, as I found in 1841. Lamplight and other artificial lights are often peculiarly energetic. These decomposing effects take place on those portions of the substance only on which the rays actually fall. There is no lateral spreading, nothing analogous to conduction.

When a sensitive substance receives light for a short space of time, no change takes place, the rays are being actively absorbed; but as soon as that preliminary absorption is over, they act in a manner which is perfectly definite; if, for instance, it be a decomposition they are bringing about, the amount of decomposing effect will be precisely proportional to the quantity of rays absorbed.

When a beam from any shining source causes a decomposing effect, it is always itself disturbed; the medium which is changing impresses a change on the ray. Thus, a mixture of chlorine and hydrogen unites under the influence of a ray, but that portion of the ray which passes through the mixture has lost the quality of ever bringing about a like change again.

When a beam from any shining source falls on a changeable medium, a portion of it is absorbed for the purpose of effecting the change, and the residue is either reflected or transmitted, and is perfectly inert as respects the medium itself.

No chemical effect can therefore be produced by such rays except they be absorbed. It is for this reason that water is never decomposed by the sunshine, nor oxygen and hydrogen made to unite; for these substances are all transparent, and allow the rays to pass without any absorption, and absorption is absolutely necessary before chemical action can ensue.

But with chlorine the case is very different. This substance exerts a powerful absorbent action on light; the effect takes place on the more refrangible rays; when mixed

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Give examples of the chemical action of light. Do artificial lights possess that property? What is meant by preliminary absorption? What change is impressed on the ray? Does the ray undergo absorption? Why can not water be decomposed in the sunshine?

with hydrogen and set in the light, it unites with a violent explosion.

The process of the Daguerreotype is conducted as follows: A piece of silver plate is brought to a high polish by rubbing it with powders, such as Tripoli and rotten-stone, every care being taken that the surface shall be absolutely pure and clean, a condition obtained in various ways by different artists, as by the aid of alcohol, dilute nitric acid, &c. This plate is next exposed in a box to the vapor which rises from iodine at common temperatures, until it has acquired a golden yellow tarnish; it is next exposed, in the camera obscura, to the images of the objects it is designed to copy, for a suitable space of time. On being removed from the instrument, nothing is visible upon it; but on exposing it to the fumes of mercury, the images slowly evolve themselves.

To prevent any farther change, the tarnished aspect of the plate is removed by washing the plate in a solution of hyposulphite of soda, and finishing the washing with water: it can then be kept for any length of time.

Several important improvements on the original process have been made: 1st, by exposing the plate, after it has been iodized, to the vapor of bromine, or chloride of iodine, which gives it a wonderful sensibility; 2d, by gilding the plate, after the other operations are complete, by the aid of a mixture of hyposulphite of soda and chloride of gold; this acts like a varnish, fastening the picture, and giving it a more agreeable yellow tone.

The art of taking portraits from the life, which has now become a branch of industry, was invented by me soon after the Daguerreotype was known in America; at that time, this, which is by far the most valuable application of the chemical agencies of light, was looked upon in Europe as entirely beyond the powers of this process; but subsequently great improvements in it have been made. My memoir descriptive of the art may be seen in the *London and Edinburgh Philosophical Magazine* (September, 1840), and the facts are also specified in the *Edinburgh Review* (January, 1843), in which the discovery is attributed to its proper source, the author of this book.

Why do chlorine and hydrogen explode? Describe the process of the Daguerreotype. Are the images visible at first? By what means are they brought out? How is the picture preserved from farther change? Mention some of the later improvements of the process.

When a beam falls upon the surface of a Daguerreotype plate, it communicates to the iodide of silver a tendency to decomposition, but iodine is never set free because of the metallic silver behind. On exposing a surface disturbed in this manner to the vapors of mercury, entire decomposition of the iodide ensues, its silver unites with the mercury, forming a white amalgam, and the iodine corrodes the metallic silver behind. The utmost care must be taken in all Daguerreotype processes to have no vapors of iodine, or bromine, or chlorine about the camera or other apparatus; they possess the quality of effacing the effects of light, and the most common source of failure among Daguerreotype artists is due to neglecting this precaution.

There are some important difficulties to which the Daguerreotype is liable. For taking landscapes it is not available. Green and red colors impress no change upon it The order of colors and light and shadow is not, therefore, strictly observed.

There are many other photogenic processes now known: several have been invented by Mr. Talbot; among them may be mentioned the calotype. Sir J. Herschel, also, has discovered very beautiful ones, and these possess the great advantage over Daguerre's, that they yield pictures upon paper. In minuteness of effect they can not, however, be compared to the Daguerreotype.

LECTURE XXIV.

THE CHEMICAL ACTION OF LIGHT.—*Fixed Lines.—Phosphorescence.—Decomposition of Carbonic Acid.—Spectral Impressions.—Effects of Amplitude, Frequency, and Direction.—Cause of Chemical Decompositions by Light.*

THE fixed lines discovered in the luminous spectrum, as represented in *Fig.* 63, also occur in the impressions left upon sensitive surfaces on which the spectrum is received,

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In this process, is iodine set free from the plate? With what does the iodine unite under the influence of the mercurial vapor? Why is not the Daguerreotype applicable to landscapes? Mention other processes of photogenic drawing. Can the fixed lines be depicted on sensitive surfaces?

as was discovered by M. Becquerel and myself about the same time (1842). In this instance, however, they are far more numerous, and occur in groups of many hundreds beyond the visible limits of the violet ray.

It has already been mentioned that light causes the phosphorescence of most bodies. Thus, if oyster-shells be calcined with sulphur and exposed to the sun, they shine for a considerable time after in the dark. Nor does it require that the time of exposure should be protracted; the flash of an electric spark is sufficient. But, what is very remarkable in this case, the rays which excite the phosphorescence can not pass through a piece of colorless glass; to them it is quite opaque. The experiments of Mr. Wilson show that a great number of bodies not commonly supposed to be phosphorescent are so in reality; that for a few moments after they have been exposed to the sun, they emit a phosphorescent light. Thus a sheet of writing paper, on which a key had been laid, having been exposed for a few moments to the sun, on being suddenly removed to a dark room, emitted a pale light, the shadow of the key being perfectly visible. Even the hand, after being dipped in the sunshine, emitted subsequently light enough to be visible in a dark place.

The various principles of which we have been speaking exert no ordinary control over the phenomena of the natural world. Thus it is to the influence of light that the vegetable world owes its existence; for plants can only obtain carbon from the air while the sun is shining on them, and it is of that carbon that their solid structures are chiefly formed. It has been a question to which ray this effect is due; but in 1843 I proved that it is the yellow light which is involved. Dr. Priestley discovered that the leaves of plants will effect the decomposition of carbonic acid gas under water; and on immersing tubes filled with water holding this gas in solution, and containing a few green leaves, I found that at the blue extremity of the spectrum no effect whatever took place, while decomposition went on rapidly in the yellow ray.

As connected with the minute changes of surface which are effected when the different radiant principles fall upon bodies, as in the instance of the Daguerreotype, we may here allude to the formation of *spectral impressions*, which,

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What is Mr. Wilson's experiment? What ray effects the decomposition of carbonic acid? What are spectral impressions?

though invisible, may be brought out by proper processes. One of these I described several years ago. Take a piece of polished metal, glass, or japanned tin, the temperature of which is low, and, having laid upon it a wafer, coin, or any other such object, breathe upon the surface; allow the breath entirely to disappear; then toss the object off the surface and examine it minutely; no trace of any thing is visible, yet a spectral impression exists on that surface, which may be evoked by breathing upon it. A form resembling the object at once appears, and, what is very remarkable, it may be called forth many times in succession, and even at the end of many months. Other instances of the kind have subsequently been described by M. Moser.

ON THE CHEMICAL ACTION OF LIGHT.

In considering the action of a ray of light upon a decomposable body, there are three different points to be discussed, so far as the ray itself is concerned: 1st. To what extent, and in what manner, is the result affected by the *intensity* of the ray; *i. e.*, by the *amplitude* of the vibrating excursions? 2d. How is it affected by the *frequency* of the pulsatory impressions? 3d. How by the *direction* in which the vibrations are made, as involved in the idea of polarization?

1st. By means of burning lenses I found that it is not the *intensity* of a beam which determines its decomposing power, and that we can not produce greater effects by concentrated light than we can by the application of the simple sunbeam continued for an equivalent period of time. Nor can such optical contrivances effect the decomposition of substances on which a feeble beam has no action.

2d. Rays of the highest refrangibility, and, therefore, of the most *frequent* vibrations, commonly have the greatest activity. On the number of impulses a ray can communicate in a given period of time, depends its power of destroying the constitution of any group of atoms. And the phenomena of interference arising from the superposition of wave motions occur exactly as might have been predicted.

3d. The *direction* of wave motion as involved in the idea of polarization, whether plane or circular, seems to exert no effect.

How far does the chemical action of a ray depend on amplitude? How far on wave-length or frequency? How far on the polarized condition?

The immediate cause of the decomposition of substances by the agency of light is, that the rays forcing the material particles on which they fall into a state of rapid vibration, in many compound molecules the constituent atoms can no longer exist together as the same group, because of the impossibility of their being animated by conspiring motions, and dislocation, rearrangement, or decomposition is the result.

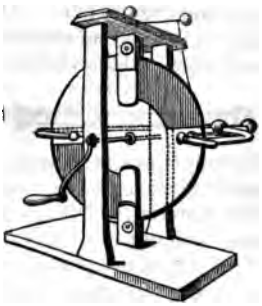
LECTURE XXV.

ELECTRICITY.—*First Observations in Electricity.—Description of Electrical Machines.—The Spark a Test of Electrical Excitement.—Repulsion of Electrified Bodies.—Simple Means of Excitement.—Conductors and Non-conductors.—Insulation.—Electric Effects take place through Glass.—Medicated Tubes.*

IT was observed, six hundred years before Christ, that a piece of amber, when rubbed, acquired the quality of attracting light bodies. This fact remained without value for more than two thousand years, a striking memorial of the barren nature of the philosophy of those times. Within the last two hundred years it has given birth to an entire group of sciences, and established the existence of an imponderable principle, which, from the Greek word ηλεκτρον, signifying amber, has taken the name ELECTRICITY.

The catalogue of substances in which electric development can be produced was greatly increased by Gilbert, who showed that glass, resin, wax, and many other bodies are equally effective as amber. To his successors we owe the electrical machine, an instrument which enables us readily to demonstrate the properties of electricity.

Fig. 75.



Electrical machines are of different kinds. They may, however, be divided into plate and cylinder

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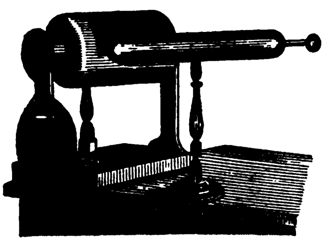
What is the immediate cause of decomposition by the agency of light? What was the first observation made in electricity? From what does the agent derive its name? What varieties of electrical machines have we?

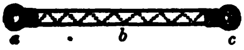
machines. These instruments are respectively represented in *Fig.* 75 and *Fig.* 76. In each of them there are three distinct portions. First, a piece of glass, the shape of which differs in different cases; in *Fig.* 75 it is a circular plate, in *Fig.* 76 a cylinder; and from these the instruments take their name. Second, the rubbers, made of silk or leather, stuffed with hair: the office of these is to press lightly on the glass as it turns round, and produce friction. Third, a brass body, of a cylindrical or rounded shape, but with points on that portion of it which looks toward the glass. It is supported on glass props, and is termed the prime conductor. Some mechanism, such as a winch, is required to turn the glass on its axis; and when it is desired to bring the machine into activity, all the parts of it having been made thoroughly clean and dry by rubbing with a piece of warm silk or flannel, a little Mosaic gold or amalgam of zinc being spread on the rubber, as soon as the winch is turned the instrument becomes excited.

Fig. 76.



One of the most striking manifestations of electrical development is the spark; this, which must have been often seen when the back of the domestic cat is rubbed on a frosty night, was discovered in the case of glass or sulphur by Otto Guericke, and by him referred to its proper source, electric excitement. On presenting a brass ball or the finger to the prime conductor of the machine, the spark passes, attended with a slight report. It may be very beautifully shown by pasting small pieces of tinfoil round a glass tube in a spiral form, as shown in *Fig.* 77, *a b c*, distances of the twentieth of an inch intervening between each piece, and the ends of the tube terminated by balls. On presenting one of these balls to the prime conductor, and holding the other in the hand, as the spark passes, it has to leap over each interstice between the spangles of tinfoil, and exhibits a beautiful spiral line of light.

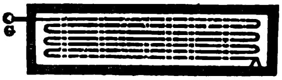
Fig. 77.



What are the three essential parts of these machines? What is the rubber? What is the prime conductor? How is the machine excited? How may the electric spark be exhibited?

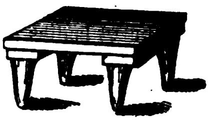
By pasting the tin-foil on a pane of glass in such a way as to direct the spark properly, words may be written in electric light, as shown in *Fig*. 78.

Fig. 78.



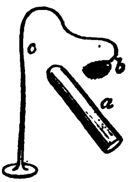
As the electric spark can hardly be confounded with any other physical phenomenon whatever, its presence is always indubitable evidence of electric excitement. Thus we can prove that electricity may be transferred to the human body from the machine, by placing a man on a stool supported by glass pillars, *Fig*. 79. If he touches the prime conductor with one hand, sparks may be drawn from any part of his clothing or body.

Fig. 79.



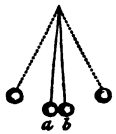
To Otto Guericke, who was also the inventor of the air pump, we owe another of the most important discoveries in electricity: that bodies which have touched an excited substance are subsequently repelled by it; thus, if we rub a glass tube, *Fig*. 80, *a*, until it becomes electrified, and then present it to a feather, *b*, suspended by a silk thread to a stand, *c*, the feather is at first attracted, and then immediately repelled.

Fig. 80.



On this principle, that under certain circumstances repulsion takes place, are founded different methods for ascertaining the existence of electric excitement, when too feeble to cause a spark. Thus two light balls of cork, *Fig*. 81, *a b*, suspended by linen threads so as to hang side by side, as soon as they are electrified, repel each other.

Fig. 81.

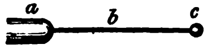


It does not, however, require an electrical machine to demonstrate the principles of this agent. A piece of stout brown paper three inches wide, and a foot long, if held before the fire until it is quite dry and smokes, and then drawn between the knee and the sleeve, becomes highly excited, especially if the person wears woolen clothing. It will yield sparks more than an inch long.

Let *a*, *Fig*. 82, be the termination of the prime conduct-

Why may it be used as a test for electric excitement? Can electricity be transferred from the machine to the body? What discovery did Otto Guericke make in electricity? How may this property of repulsion be illustrated? By what simple means may electrical experiments be made?

Fig. 82.



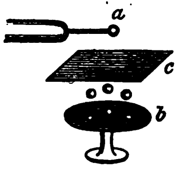
or, and in a hole in it place the long brass rod *b*, terminated by the brass ball *c*. If the finger is approached to the ball, sparks freely pass, showing that along brass electricity is conducted; but if a glass rod of the same diameter and length, and terminated by a brass ball, be employed, not a solitary spark can be obtained, proving that glass is a non-conductor of electricity.

The important fact that substances may be divided into two classes, conductors and non-conductors, was first accidentally discovered by Dr. Grey, who found that all metals and moist bodies are conductors, and that glass, resins, wax, sulphur, atmospheric air, are non-conductors. In the treatises on chemistry, tables may be found exhibiting the relations of bodies in this respect. The conducting power of the same substance differs with circumstances; thus ice and glass are non-conductors, but water and melted glass are conductors.

We see, from these facts, the explanation of the structure of the prime conductor; the electricity derived from the glass by friction passes easily along the brass portion, but can not escape into the earth, owing to the glass supports which refuse it a passage. When a body is thus placed upon glass, it is said to be electrically insulated, and the process is called insulation.

Although electricity can not pass through glass, Sir Isaac Newton found that this substance is no impediment to the exertion of its influences. Thus, in *Fig.* 83, if *a* be the brass ball of the prime conductor, any light objects, such as bits of paper or fragments of cork, placed on a metal stand, *b*, beneath, will be attracted; and though a pane of glass, *c*, be placed between *a* and *b*, still the same phenomenon takes place.

Fig. 83.



Soon after electricity became a subject of popular attention, it was currently believed that, if medicines of various kinds were sealed up in glass tubes, and the tubes electrically excited, their peculiar virtues would be exhaled in such

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How may it be proved that brass is a conductor and glass a non-conductor? Mention some of the leading substances belonging to each of these classes. Explain the structure of the prime conductor. Can electric influences pass through glass? What was formerly meant by medicated tubes?

a manner as to impress the operator with their specific purgative, emetic, or other powers. Like many of the popular delusions of our times, this imposture was supported by the most cogent evidence, and maladies cured publicly all over Europe. Like them, these "medicated tubes" have served to prove the worthlessness of human testimony when derived from the prejudiced and ignorant.

It should be remarked that, in their action upon material bodies, electricity and caloric differ greatly. The former has no kind of influence in determining magnitude, whereas the size of any object depends upon its temperature.

LECTURE XXVI.

THEORY OF ELECTRICAL INDUCTION.—*Two Species of Electricity.—Their Names.—General Law of Attraction and Repulsion.—Theory of Induction.—Permanent Excitement by Induction.—Takes place through Glass.—Illustrative Experiments.*

A VERY celebrated French electrician, Dufay, having caused a light, downy feather to be repelled by an excited glass tube, intended to amuse himself by chasing it round the room with a piece of excited sealing-wax. To his surprise, instead of being repelled, the feather was at once attracted. On examining the cause of this more minutely, he arrived at the conclusion that there are two species of electricity, the one originating when glass is excited, and the other from resin or wax. To these he gave the names of vitreous and resinous electricity, thus pointing out their origin; they are also called, for reasons which will be given hereafter, positive and negative electricities.

He found that these different electricities possess the same general physical qualities; they are self-repulsive, but the one is attractive of the other. This is readily proved by hanging a feather by a linen thread to the prime conductor of the machine, and, when it is excited, bringing near to it

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Does electricity affect the magnitude of bodies? How was it first discovered that there are two species of electricity? What names have been given to these electricities? What are their physical qualities? How may this self-repulsion and mutual attraction be proved?

an excited glass tube. The feather is already vitreously electrified, and the tube, being in the same condition, at once repels it; but a stick of excited sealing-wax being resinously electrified, that is to say, in the opposite condition to the feather, at once attracts it. Two cork balls, as in *Fig.* 81, suspended by conducting threads, always repel one another when both are excited either vitreously or resinously; but if one be vitreous and the other resinous, they attract.

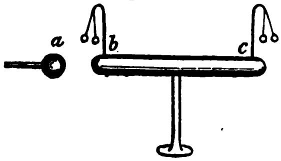
These various results may all be grouped under the following general law, which includes the explanation of a great many electrical phenomena. Bodies electrified dissimilarly attract, and bodies electrified similarly repel; or, more briefly, like electricities repel, and unlike ones attract.

There are many ways in which electrical excitement can be developed: in the common machine it is by friction; in the tourmaline, a crystallized gem, by heat; and in other cases, by chemical action and by conduction. Electrical disturbance also very often arises from induction.

By the term *electrical induction* we mean that a body which is already excited tends to disturb the condition of others in its neighborhood, inducing in them an electric condition.

Thus, let *a*, *Fig.* 84, be the terminal ball of the prime conductor, and a few inches off let there be placed a secondary conductor, *b c*, of brass supported on a glass stand, and at each extremity, *b* and *c*, of the conductor, let there be arranged a pair of cork balls suspended by linen threads, as shown in the figure.

Fig. 84.



As soon as the ball, *a*, is electrified by turning the machine, and without any spark passing from it to the secondary conductor, the balls will begin to diverge, showing that the condition of that conductor is disturbed by the neighborhood of the excited ball, *a*.

It will farther be found, on presenting an excited piece of sealing wax to the pairs of cork balls, that one set is attracted, and the other repelled. They are, therefore, in op-

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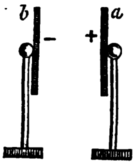
What is the general law of electric attractions and repulsions? In what ways may electric excitements be developed? What is the meaning of electric induction? Give an illustration. In a secondary conductor disturbed by an electrified body, what are the conditions of its ends?

posite electrical states. The disturbing ball is vitreously electrified, and that end of the secondary conductor nearest it is resinous, the farther end being vitreous. If the disturbing ball, *a*, be now removed, the electric disturbance ceases, and the corks no longer diverge.

Fig. 85.

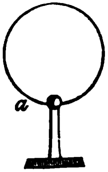


These phenomena of electric induction are not dependent on the shape of bodies. Let there be two flat circular plates, *a b*, *Fig.* 85, supported on glass stands, and set a few inches apart, looking face to face. Let one of them, *a*, be electrified positively by contact with the prime conductor, as indicated by the sign + ; it immediately induces a change in the opposite plate, the nearest face of which becomes negative —, and the more distant, positive. It is evident that this disturbance is a consequence of the law, that " like electricities repel, and unlike ones attract." In the plate *b*, both species of electricity exist, and *a* being made positive, even though at a distance, exerts its attractive and repulsive agencies on the electric fluid of *b*, the negative electricity of which it attracts, and draws near to it; the positive it repels and drives to the farthest side; so that the disturbed condition of the body *b* is a result of the fact, that *a* being electrified positively, will repel positive electricity and attract negative.

Now let the plate *b* be touched by the finger, or a channel of communication opened with the earth; the positive electricity of *a* still exerting its repulsive agency on that of *b*, will drive it into the ground, and *b* will now become negative all over.

Let *b* be once more insulated by breaking its communication with the ground, and let *a* be removed; it will now be found that *b* is permanently electrified, and in the opposite condition to *a*.

Fig. 86.



By manipulating in this manner, we can therefore effect a permanent disturbance in the condition of an insulated body, by bringing an excited one in its neighborhood.

In these changes, the intervention of a piece of glass makes no difference. Let a circular plate of glass, *a*, *Fig.* 86, be set so as to intervene be-

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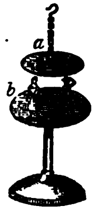
What is the cause of this disturbance ? How may we by induction permanently electrify a body ? Can electrical induction take place through glass ?

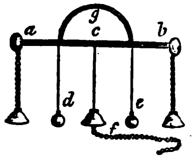
tween the metallic plates, *a* and *b*, and still all the phenomena occur as before. Electric induction, therefore, can take place through glass.

Fig. 87.



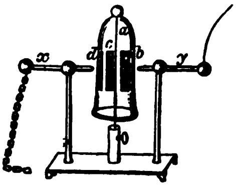
On the principles of induction, and of electric attraction and repulsion, many very interesting experiments may be explained. The following may serve as examples: To the ball of the prime conductor, *Fig.* 87, let there be suspended a circular plate of brass, *a*, six inches in diameter, horizontally, and beneath it another plate, *b*, supported on a conducting foot, parallel and at a distance of three or four inches. On the lower plate, *b*, place slips of paper or of other light substance, cut into the figure of men or animals. On setting the machine in motion, so as to electrify the upper plate, the objects move up and down with a dancing motion; and the cause is obvious: the plate *a* being positive, repels by induction the positive electricity of the figures through the conducting stand into the earth, and thus, they being rendered negative, are attracted by the upper plate; on touching it, they become electrified positively like it, and then are repelled, and fall down to discharge their electricity into the ground, and this motion is continually repeated.

Fig. 88.



Upon a horizontal brass bar, *a b*, *Fig.* 88, three bells are suspended, the outer ones at *a* and *b* by chains, the middle one at *c* by a silk thread. Between the bells, the metallic clappers, *d e*, are suspended by silk, and from the center bell the chain *f* extends to the table. On hanging the arrangement by the hook at *g* to the prime conductor, the bells ring, the clappers moving from the outer to the central bell and back, alternately striking them.

Fig. 89.



On a pivot, *a*, *Fig.* 89, suspend a bell jar having four pieces of tin-foil pasted on its sides, *b c d;* connect the jar, by means of the insulated wire *y*, with the prime conductor, so that the pieces of tin-foil

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Describe the experiment of the dancing figures, and explain the principles involved in it. Describe the experiment of the bells, and the cause of their ringing. **Explain the arrangement and cause of movement of the rotating jar.**

may receive sparks. On the opposite side arrange a conductor, *x*, in connection with the ground by a chain. On putting the machine into activity, the jar will commence rotating on its pivot.

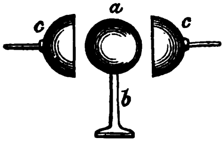
Take a cake of sealing wax or gum lac, eight or ten inches in diameter, and receive on its surface a few sparks from the prime conductor by bringing it near the ball. Then blow upon its surface from a small pair of bellows a mixture of flour of sulphur and red lead, which have been intimately ground together in a mortar. This mixture is of an orange color, but the moment it impinges on the cake it is, as it were, decomposed; the yellow sulphur settling on one portion, and the red lead on another, giving rise to very curious and fantastical figures.

LECTURE XXVII.

LAWS OF THE DISTRIBUTION OF ELECTRICITY, AND THE GENERAL THEORIES.—*Distribution of Electricity.—On a Sphere.—Ellipsoid.—Action of Points.—Franklin's Discovery of the Identity of Electricity and Lightning.—The Leyden Jar.—The Discharging Rod.—The Electric Battery.*

WHEN electricity is communicated to a conducting body, it does not distribute itself uniformly through the whole mass, but exclusively upon the surface; thus, if to the spherical ball *a*, *Fig.* 90, supported on an insulating foot, *b*, there be adjusted two hemispherical caps, *c c*, also on insulating handles, it may be proved that any electricity communicated to *a* distributes itself entirely on its surface; for if we place upon *a* the caps *c c*, and then remove them, it will be found that every trace of electricity has disappeared from *a*, and has accumulated on the caps, which, while they were upon the ball, formed its superficies.

Fig. 90.



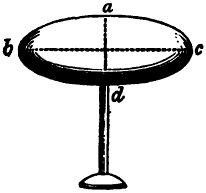
How may powder of sulphur and red lead mixed together be separated? Does electricity distribute itself on the surface or in the interior of bodies? How may its superficial distribution be proved?

Fig. 91.

Again, if we take a large brass ball, *a*, *Fig.* 91, supported on an insulating stand, and having on its upper portion an aperture, *b*, through which we may have access to its interior, it will be found, on examination, that the most delicate electrometers can discover no electricity within the ball, the whole of it being on the external superficies.

In the case of a spherical body, not only is the distribution entirely superficial, but it is also uniform; each portion of the sphere is electrified alike. But where, instead of a spherical, we have an ellipsoidal body, it is different; thus, if we examine the condition of such a conductor, *Fig.* 92, the quantity of electricity in its middle portion, as at *a*, will be the smallest, and it increases as we advance toward the ends, *b* and *c*; and in different ellipsoids, as the length becomes greater, so the amount of electricity found on the extremities is greater. When, therefore, a conductor of an oblong spheroidal shape is used, the intensity of electricity at the extremities of the two axes, *a d* and *b c*, *Fig.* 92, is exactly in the proportion of the length of those axes themselves; and should the disproportion in length and breadth of the conducting body be very great, as in the case of a long wire or other pointed body, a very great concentration will take place upon the points. On this principle we explain the effect of pointed bodies on conductors: if the prime conductor of the machine have a needle or pin fixed upon it, the electricity escapes away into the air, visibly in a dark room; and in the same way, if pointed bodies surround the electrical machine, it can not be highly excited, as they rapidly take the charge from its conductor.

Fig. 92.



At a very early period electricians had observed the close similarity between the phenomena of the electric spark and those of lightning, but in the year 1752 Dr. Franklin proved that they were identical. He was waiting for the erection of the spire of a church in Philadelphia, on the extremity of which he intended to raise a pointed metal rod, with a

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In the interior of an electrified hollow ball, does any electricity exist? On a spherical body, is the distribution uniform? How is it on an ellipsoid? When the disproportion of the axes of the ellipsoid is great, what is the distribution? How may we explain the effect of pointed bodies?

view of withdrawing the electricity from the clouds, when the accidental sight of a boy's kite suggested to him that ready means of obtaining access to the more elevated regions of the air. Accordingly, having stretched a silk handkerchief over a light wooden cross, and arranged it as a kite, he attached to it a hempen string terminating in a silk cord, and, taking advantage of a thunder storm, raised it in the air; for a time no result was obtained, but the string becoming wet by the rain, and thereby rendered a better conductor, he perceived the filaments which hung upon it repelling one another, and on presenting his knuckle to a key which had been tied to the end of the hempen string, received an electric spark. The identity of lightning and electricity was proved.

Franklin soon made a useful application of his discovery; he proposed to protect buildings from the effects of lightning by furnishing them with a metallic rod, pointed at its upper extremity, and projecting some feet above the highest part of the building, and continuously extending downward until it was deeply buried in the ground. This contrivance, the lightning rod, is now, as is well known, extensively applied.

There are two theories respecting the nature of electricity: 1st, Franklin's theory, which assumes that there is but one fluid; 2d, the theory of two fluids, called also Dufay's theory.

Franklin's theory is, that there exists throughout all space a subtle and exceedingly elastic fluid, called the electric fluid, the peculiarity of which is, that it is repulsive of its own particles, but attractive of the particles of other matter; that there is a specific quantity of this fluid which bodies are disposed to assume when in a natural condition or state of equilibrium; and that, if we communicate to them more than their natural quantity, they become positively electrified; or, if we take from a portion of that which is natural to them, they become negatively electrified.

Dufay's theory is, that there exists throughout all space a universal medium, called the electric fluid, of which the immediate properties are unknown, but which is composed of two species or varieties of electricity, the vitreous and

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Under what circumstances was the discovery of the identity of lightning and electricity made? What is the lightning rod? What theories of electricity have been introduced? What is Franklin's theory? What is the theory of Dufay?

resinous, called also the positive and negative; that, as respects itself, each of these electricities is repulsive, but attractive of the other kind; and that, when they coexist in equal quantities in a body, it is in a neutral state or condition of equilibrium, but if the positive or negative electricities are in excess, it is accordingly positively or negatively electrified.

In some respects the theory of two electricities has advantages over that of one; by it several phenomena can be explained which are difficult of explanation by the other. Among such may be mentioned the repulsion of negatively electrified bodies, and the distribution of negative electricity on the surface of conductors, which is the same as that of positive.

On the principles of either of these theories, we can see how it is that we can never produce one kind of electricity without the other simultaneously appearing. In the common electrical machine, if the revolving glass is positively electrified, the rubbers which produce the friction are negative; in the tourmaline, if one end of the crystal, when warmed, becomes positive, the other end is negative. The two varieties must be always co-ordinately generated.

Fig. 93.

In 1745 the Leyden jar was discovered. This consists of a glass jar, *Fig.* 93, coated on its inside with a piece of tin-foil within an inch or two of its upper edge, and also on its outside to the same point; through the cork which closes the mouth of the jar, a brass rod, terminated by a ball, passes; the rod reaches down to the inside coating and touches it. On holding this instrument by the exterior coating, and presenting its ball to the prime conductor, a torrent of sparks passes into the jar: and when it is fully charged, if, still retaining one hand in contact with the outside, we touch the ball, a bright spark passes, with a loud snapping noise, and the operator receives through his arms and breast what is called the electric shock.

If we take the discharging rod, *Fig.* 94, consisting of two brass arms, *a a*, terminated by balls working on a joint, *b*,

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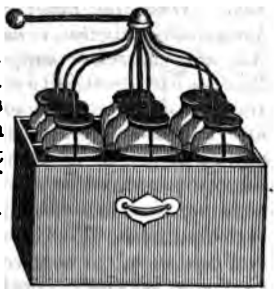
In what points does the latter appear to be more correct than the former? Why are both electricities always produced together? Describe the structure of the Leyden jar. How may it be used? Describe the discharging rod.

and supported by an insulating handle, *c*, by bringing one of its balls in contact with the outside coating of a Leyden jar, and its other ball with the ball of the jar, the discharge will take place as before, but the operator, protected by the glass handle, receives no shock.

Fig. 94.

If between the outside coating of a jar and one of the balls of the discharging rod a piece of card-board is made to intervene, and the spark passed, the card will be found to be perforated, a burr being raised on both sides of it, as though two threads had been drawn through the hole in opposite directions at the same time; and from this an argument in favor of the theory of two fluids has been drawn.

Fig. 95.



When a great number of jars are connected together, so that all their inside coatings unite, and all their outside coatings are also in contact, they constitute what is termed an electric battery, as seen in *Fig.* 95. By this instrument many of the more violent effects of electricity may be illustrated, such as the splitting of pieces of wood, and the ignition and dispersion of metallic wires.

LECTURE XXVIII.

ELECTRICAL INSTRUMENTS AND FARADAY'S THEORY OF ELECTRIC POLARIZATION. — *Theory of the Leyden Jar.* —*Quadrant, Gold-leaf, and Torsion Electrometers.*— *Theory of Electric Polarization.* — *Specific Inductive Capacity.*

THE office which is discharged by the metallic coatings of a Leyden jar is illustrated by the apparatus, *Fig.* 96. It consists of a conical glass jar, to the interior and exterior

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How is it used? What is the effect when the discharge is passed through a piece of card-board? Describe the electric battery. What is the office of the coatings of the Leyden jar?

of which movable coatings of thick tin plate are adapted, the interior one having a rod and ball projecting from it. This may be charged like any other Leyden vial, but on taking off its outside coating and removing its interior, they may be handled and brought in contact with each other, and no spark passes; but on restoring them to their former position, and applying the discharging rod, the jar is discharged. They therefore only serve to make a complete conducting communication between all parts on the interior and all on the exterior of the jar.

Fig. 96.

The condensing action of the Leyden vial, which enables it to hold so large a quantity of electricity, is due to induction. When the inner coating is brought in contact with the prime conductor, it participates in its electrical condition. We may therefore suppose it to be positively electrified. The positive electricity of the interior, decomposing the electric fluid of the outside coating, repels its positive electricity into the earth; for to charge a Leyden vial the outside coating is placed in communication with the ground. It therefore appears that the inner coating is positive, the outer negative, and the whole jar, viewed together, is in the neutral condition. The interior coating continues, under these circumstances, to receive a farther charge from the prime conductor; by induction through the glass, this again repels more of the same kind, the positive, into the ground, and the negative accumulates as before. In this manner an indefinite quantity might be accumulated, were it not for the fact that, owing to the distance which intervenes between the two coatings, by reason of the thickness of the glass, the quantity of positive electricity in the interior is never precisely neutralized by the quantity of negative on the exterior, for all inductive actions enfeeble as the distance increases.

The action of the Leyden vial may be illustrated by the following experiments: within an inch of the ball, *a*, of the prime conductor, *Fig.* 97, bring a secondary conductor, *b*, supported on an insulating stem, *c*, and on putting the

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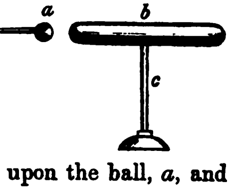
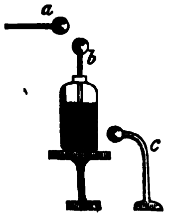
How may this be proved? To what cause is the condensing action of the Leyden jar due? What is the action of the positive electricity deposited on the inner coating, on the electric fluid of the outer? Why must the outer coating be in connection with the ground? Why is the charge of the jar limited?

Fig. 97.



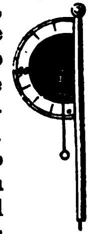
electrical machine in activity, two or three sparks will pass from *a* to *b*, but after that no more. The cause of the refusal, on the part of the secondary conductor, to receive any farther charge, is obviously due to the fact that the electricity which is already communicated to it repels that upon the ball, *a*, and prevents the passage of any more.

Fig. 98.



If now we take a Leyden jar *b*, *Fig.* 98, and, having insulated it on a stand, bring it within a short distance of the ball, *a*, of the prime conductor, it in the same manner will only receive a few sparks. But if we place a conductor, *c*, which is connected with the ground, near to the outside coating, it will be found that for every spark that passes between *a* and *b*, one passes between the outside coating and *c*, and the sparks follow each other in rapid succession, until the jar becomes fully charged. From this, therefore, we gather, that while positive electricity is passing into the interior of the jar, it is escaping from the exterior, and that the reason the jar condenses is because its sides are in opposite conditions, the positive electricity of the interior being nearly neutralized by the negative electricity of the exterior.

Fig. 99.



Electrometers are instruments for measuring the intensity of electric excitement. The cork balls, which were represented in *Fig.* 81, are one of the most simple of these contrivances. The distance to which they will diverge is a rough measure of the intensity of the electric force. The quadrant electrometer depends essentially on the same principles. It consists of an upright stem of wood, *Fig.* 99, to which is affixed a semicircular piece of ivory, from the centre of which there hangs a light cork ball playing upon a pivot. When this instrument is placed on the prime conductor or other electrified body, the stem participates in the electricity, and, repelling the cork

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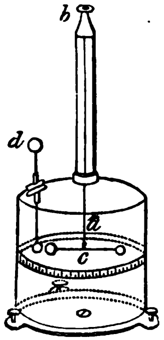
What is the reason that a secondary insulated conductor refuses to receive more than two or three sparks? When the Leyden jar is insulated, can it be charged? On bringing a conductor in connection with the ground, near the outer coating, what is the result? Describe the cork ball electrometer. Describe the quadrant electrometer.

ball which hangs in contact with it, the amount of repulsion may be read off on the graduated semicircle; but it is obvious that the number of degrees is not expressive of the true electrical intensity, and that no force, no matter what its intensity may be, can ever repel the ball beyond ninety degrees.

Fig. 100.

The gold-leaf electrometer, *Fig.* 100, consists of a glass cylinder, *a*, in which two gold leaves are suspended from a conducting rod terminated by a ball or plate, *b*. On the glass opposite the leaves pieces of tin-foil are pasted, so that when the leaves diverge fully they may discharge their electricity into the ground. This is a very delicate instrument for discovering the presence of electricity, but the torsion electrometer of Coulomb is to be preferred when it is required to have exact measures of the quantity.

Fig. 101.



Coulomb's electrometer consists of a glass cylinder, *a*, *Fig.* 101, upon the top of which there is fixed a tube, *b*, in the axis of which hangs a glass thread, *b a*, to the lower end of which a small bar of gum lac, *c*, with a gilt pith ball at each extremity, is fastened. Through an aperture in the top of the glass cylinder, another gum lac rod, *d*, with gilt balls, may be introduced. This goes under the name of the carrier rod.

If now the lower ball of the carrier rod be charged with the electricity to be measured, and introduced into the interior of the cylinder, as seen in the figure, it will repel the movable ball. By taking hold of the button, *b*, to which the upper end of the glass thread, *a*, is attached, we may, by twisting the glass thread forcibly, bring the carrier ball and the movable ball in contact. The number of degrees through which the thread requires to be twisted represents the amount of electricity. To the button, *b*, an index and scale are attached, not shown in the figure. By this we can tell the number of degrees of twist or torsion which have been given to the

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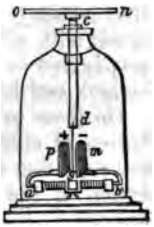
Why does the quadrant electrometer give inaccurate indications? Describe the gold leaf electrometer. Describe Coulomb's torsion electrometer.

thread. These angles of torsion are exactly proportional to the quantities of electricity.

One of the most delicate electroscopes is that of Bohnen, berger. It consists of a small Zamboni's pile, *a b*, *Fig.* 102, supported horizontally beneath a glass shade, and from its extremities, *a b*, curved wires pass, which terminate in parallel plates, *p m*. One of these is therefore the positive, and the other the negative pole of the pile. Between them there hangs a gold leaf, *d g*, which is in metallic communication with the plate *o n* by means of the rod *c*. If the leaf hangs equally between the two plates, it is equally attracted by each, and remains motionless; but, on communicating the slightest trace of electricity to the plate *o n*, the gold leaf instantly moves toward the plate which has the opposite polarity.

Fig. 102.



Many of the fundamental phenomena of electricity have been explained by Dr. Faraday upon the hypothesis that induction is an action of polarization, taking place in the contiguous molecules of non-conducting media, and propagated in curved lines.

Whatever may be the form or constitution of bodies, an electric charge can not be given to them without at the same time giving a charge of the opposite kind, but of the same amount, to them or other bodies in their vicinity. This charge is not confined upon their surfaces by the pressure of the atmosphere, but through the polarization of the aerial or solid particles of the surrounding dielectrics, producing in them a charge of the same amount, but of an opposite kind. Thus, if a positively electrified ball be placed in the centre of a hollow metallic sphere, the intervening space being filled with atmospheric air, the charge is not retained upon the ball by the pressure of the air, but because each aerial particle assumes by induction a polarity of the opposite kind on the side nearest to the ball, and of the same kind on the side farthest off. This state of force is therefore communicated to the interior of the hollow sphere, which is electrified to the same amount, but of an opposite kind to the ball.

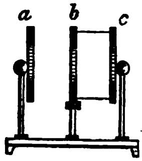
Describe Bohnenberger's electrometer. What is the basis of Faraday's theory of induction? On this theory, are charges confined by pressure of the air? Describe the action of an electrified ball in the interior of a sphere.

That this polarization of the particles takes place, is shown by the position which small silk fibres or spangles of gold assume when placed in oil of turpentine through which induction is established. Each particle disturbs not merely that which is before it or behind it, but it is in an active relation with all surrounding it, and hence the polarity can be propagated in curved lines, and induction take place round corners and behind obstacles.

On these principles, we can easily account for the distribution of electricity on spherical or ellipsoidal conductors, the repulsion of bodies similarly electrified, the condensing action of the Leyden vial, and many other similar phenomena.

By a variety of experiments, Dr. Faraday has proved that inductive action takes place in curved lines, the directions of which can be varied by the approach of bodies. He has also shown that the particles of solids, as gum lac, glass, &c., assume this character of polarity. Non-conducting bodies, through which the action of induction takes place, are *dielectrics*, and each of them has a specific inductive capacity. Thus, if three metallic plates, *a b c*, *Fig.* 103, be insulated parallel to each other, atmospheric air intervening between *a* and *b*, and a plate of gum lac between *b* and *c*, the inductive action of the gum lac will be found to exceed that of the air. The following table gives some of these results:

Fig. 103.



Inductive capacity of	air	1·00
" "	glass	1·76
" "	lac	2·00
" "	sulphur	2·24

All the gases have the same inductive capacity, whatever their density, elasticity, temperature, or hygrometric condition may be.

The electrophorus is an instrument which depends for its action on induction, and is of frequent use in chemistry. It consists of a cake of gum lac or sealing wax, *b*, *Fig.* 104, on which is placed a flat metallic plate, *a*, with an insulating

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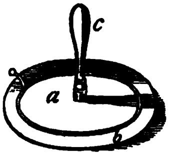
Does induction take place in straight or curved lines? Can the particles of solid bodies be polarized? What are dielectrics? What is meant by the specific inductive capacity of dielectrics? Of air, glass, and sulphur, what are the inductive capacities? What is the case with gaseous bodies? Describe the electrophorus.

handle, *c*. On exciting *b* with a piece of warm flannel, it becomes negatively electric, and *a* being placed on it, and the finger brought near, a negative spark, driven from *a* by the repulsive influence of *b*, is received. On lifting *a* by its insulating handle, a positive spark is obtained; on putting it down on *b*, a negative one. And in this manner we may obtain an unlimited number of sparks; positive ones when *a* is lifted, and negative ones when it is down. A little reflection will show that none of this electricity comes from the excited cake *b*, but is merely the effect of its inductive influence on the electric condition of the metallic plate *a*. The electrophorus may be used when the weather is too damp for the common machine to work.

Fig. 104.



LECTURE XXIX.

VOLTAIC ELECTRICITY.—*Of Electricity in Motion.—Sulzer's Experiment.—Galvani's Discovery.—Volta's Theory.—Water is a compound Body.—Description of a simple Voltaic Circle and its Properties.—Direction of the Current.—Different Kinds of Combinations.—Use of Sulphuric Acid.—Origin of the Electricity.*

DURING the last century, a German author of the name of Sulzer observed that, when two pieces of metal of different kinds, as silver and zinc, are placed one above and the other beneath the tongue, as often as their projecting ends are brought in contact, a remarkable metallic taste is perceived. To explain this result, he supposed that some kind of vibratory movement was excited in the nerves of the tongue. It is the first recorded phenomenon attributable to Voltaic electricity.

In the year 1790, Galvani, an Italian anatomist, observed the contractions which ensue when a metallic communication is made between the nerves and muscles of a dead frog; he found that, if a single metal is employed as the line of

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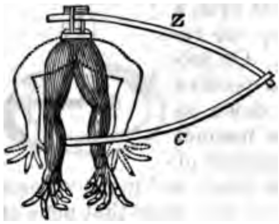
What fact was first described in Voltaic electricity? What was the fact discovered by Galvani?

communication, contractions of the muscle take place whenever the metal reaches from the nerve to the muscle; but that if two pieces of different kinds are used, the contractions are much more energetic. Thus, if we take the skinned hind legs of a frog, *Fig.* 105, hanging together by a piece of the spine, around which tin-foil has been twisted, every time that we simultaneously touch the tin-foil and the muscle with a bent copper wire, or with a copper and zinc wire, C Z, conjointly, a convulsive contraction takes place.

Fig. 105.



To explain this effect, Galvani supposed that the muscular system of animals is constantly in a positively electrical state, while the nervous system is negative. In the same manner, therefore, that a discharge takes place in the case of a Leyden vial, when a line of communication is opened between the two coatings, the muscular contractions in this case are to be accounted for. For some time these phenomena went under the name of animal electricity; they subsequently have received the designations of Galvanism and Voltaic electricity.

But Volta, another Italian philosopher, was led to suppose that the cause of this remarkable result is not due to any peculiarity of the animal system, but to the contact of the pieces of metal employed. This led to the invention of the Voltaic pile, an instrument which has achieved a complete revolution in chemistry.

It is interesting to remark what great results may, in the hands of a true philosopher, spring from the most insignificant observations. The convulsive spasms of a frog's leg have ended in showing that the entire crust of the earth is made up of metallic oxides, have revealed the mystery why the magnetic needle points to the north, and revolutionized the science of chemistry.

What we have already said in the foregoing Lectures respecting electricity refers chiefly to that agent in a motionless or stagnant state, as the mode of its distribution on con-

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In what manner did he explain it? Under what names did these phenomena successively pass? What was Volta's supposition? What is the difference between common and Voltaic electricity?

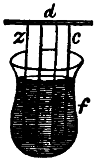
ductors, the action of the Leyden vial, &c. The phenomena of Voltaic electricity are those which arise from electricity in a state of motion.

From the great advances which these sciences have recently made, we are able to present the various topics involved in a much clearer way than by merely tracing them in a historical sketch. I shall not, therefore, pursue the order in which these facts were successively discovered, but present them in what now appears the simplest manner.

It is to be admitted, though of that abundant proof will soon be given, that water is not a simple, but a compound body; that it consists of two elements, oxygen and hydrogen gases. It is also to be understood that metallic zinc may be amalgamated or united with quicksilver, by putting it in contact with that fluid metal, under the surface of dilute sulphuric acid. Strips of zinc thus amalgamated exhibit a pure metallic brilliancy.

If now we take a strip of amalgamated zinc, an inch wide and three or four inches long, and a piece of clean copper of similar size, *z* and *c*, *Fig.* 106, and placing them side by side in a glass, *f*, containing water slightly acidulated with sulphuric acid, we have one of the forms of a simple Voltaic circle. In this, it is to be observed, that so long as the metallic plates remain without touching each other, no remarkable phenomenon appears; but if we take a metallic rod, *d*, and let it connect the top of the zinc and copper together, a series of new facts arises.

Fig. 106.



First, from the surface of the copper, bubbles of gas are evolved; they are minute, but so numerous as to make the water turbid; if collected, they are found to be hydrogen gas.

Secondly, the plate of zinc rapidly wastes away, as is easily proved by weighing it from time to time; and on examining the liquid in the cup, we discover the cause of this waste, for that liquid contains oxide of zinc; coupling this fact with the former, we infer that, so long as the metallic rod, *d*, is in its place, water is decomposed, its oxygen uniting with the zinc, its hydrogen escaping from the copper. On removing the rod, *d*, all these phenomena at once cease.

Is water a simple or a compound body? What is meant by amalgamated zinc? Describe a simple Voltaic circle. As long as the plates are not in contact, does any phenomenon take place? On communicating by a metallic rod, what gas is evolved from the copper? What happens to the zinc? Why do we infer that water is decomposed?

Thirdly, if, instead of a metallic rod, *d*, a rod of glass, or other non-conductor of electricity, be employed, no decomposition takes place. This, therefore, indicates that the agent which is in operation is electricity.

Fourthly, if for the line of communication, *d*, a piece of metal be employed, and we cautiously lift it from the zinc or copper plate, the moment the contact is broken, in a dark room, we see a minute electric spark. It has been already observed that the electric spark can not be confounded with any other natural phenomenon.

Fifthly, if the line of communication be a very slender platinum wire, as long as it remains in its position, its temperature rises so high that it becomes red hot, and may be kept so for hours together. Now, recollecting that the ignition and fusion of metals take place when they are made to intervene between the coatings of a Leyden vial, and considering all the facts which have just been set forth, we see that the following conclusion may be drawn: that in an active simple Voltaic circle water is decomposed, its oxygen going to the zinc and its hydrogen to the copper, and that a continuous current of electricity accompanies this decomposition, running from one metal to the other, through the connecting rod.

The direction of this current may be determined by several processes; it is as follows: the electricity, leaving the surface of the zinc, passes through the liquid to the copper, then moves through the connecting wire back again to the zinc, performing a complete circuit; hence the term Voltaic circle.

Simple Voltaic circles are of several kinds; that which we have been considering consists of two different metals with one intervening liquid, but similar results can be obtained with one piece of metal and two different liquids.

In the foregoing experiment we have used dilute sulphuric acid: this acid discharges a subsidiary duty. Zinc, when it oxidizes, is covered with a coating impermeable to water and air; it is this grayish oxide which protects the common sheet zinc of commerce from farther change. When, therefore, a Voltaic pair gives rise to a current by

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If a glass rod is used instead of a metallic one, what is the result? How can a spark be made visible? Can a platinum wire be ignited? From these facts, what conclusions may be drawn? What is the course of the current? What other kinds of Voltaic circles are there?

the oxydation of its zinc, that current would speedily stop were not the oxide removed as fast as it forms; this is done by the sulphuric acid, which forms with it a sulphate of zinc, a substance very soluble in water, and the metal thus continually presents a clear surface to the water.

As to the immediate cause which gives rise to the Voltaic current, there has been a difference of opinion among chemical authors. Volta believed that the mere contact of the metals was the electromotive source, and endeavored to prove, by direct experiment, that if a piece of copper and zinc are brought in contact and then separated, they become excited, the one positively and the other negatively; upon these principles, he was led to the discovery of the Voltaic battery. But many facts have now indisputably shown that the origin of the current is to be sought in the chemical changes going on; and in the instance we have had under consideration, it is due to the decomposition of water. That the electromotive action does not depend on the contact of the metals, seems to be proved by the fact that, by changing the nature of the liquid intervening between them, we can change the current both in direction and force.

LECTURE XXX.

EFFECTS OF VOLTAIC ELECTRICITY.—*Invention of the Voltaic Pile.—Cruickshank's Trough.—Hare's Battery.—Smee's Simple and Compound Battery.—Grove's Battery.—Voltaic Effects, the Spark, Deflagration of Metals.—Ignition of Wires.—Arc of Flame.—Decomposition of Water.—Nature of the Gases evolved.*

IT has been already observed that, in the discussions which arose respecting animal electricity, Volta attributed the action entirely to the metals employed, and, reasoning on this principle, he concluded that the effect ought to increase, if, instead of using a single pair of metals, a great number of alternations were employed. Accordingly, on

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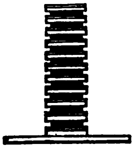
What is the use of sulphuric acid in these combinations? What was Volta's opinion as to the electromotive source? What is the view now taken? What arguments may be adduced for its correctness? How was Volta led to the invention of the pile?

taking thirty or forty silver coins and discs of zinc, and pieces of cloth moistened with acidulated water, of the same size, and arranging them in a pile or column, carefully observing to place them in the same order, silver, cloth, zinc—silver, cloth, zinc, &c., he found his expectation verified. On touching, with moistened hands, the end of the pile, a shock was at once received, and on making them communicate by a piece of wire, an electric spark passed. This instrument, *Fig.* 107, is the Voltaic pile.

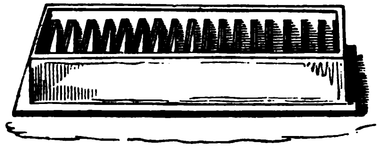
Fig. 107.



From the important uses to which the pile was soon devoted, it became necessary to have it under a more convenient form. There are several inconveniences attending the original construction: it is liable to overset, is troublesome to put in action, and requires to be taken to pieces and carefully cleaned every time it is used; its maximum effect lasts but a short time, owing to the weight of the superincumbent column pressing out the moisture from the lower pieces of cloth; and as soon as they become dry, all action ceases.

These difficulties were avoided, to a great extent, in the trough battery, which soon replaced the former instrument. It consists of a box or trough, *Fig.* 108, three or four inches square at the ends, and a foot or more long; grooves are made in the sides and bottom of this box, and into them pieces of zinc and copper, soldered face to face, are fastened, water tight, by cement. These grooves are about half an inch apart, and into their interstices acidulated water is poured, care being taken that the metals are arranged in the same direction, so that if the series begins with a copper plate, it ends with a zinc. The apparatus is obviously equivalent to Volta's pile laid on its side, and the facility for charging it, and removing the acid when the experiments are over, is very great. From the extremities two flexible copper wires pass: they are called the polar wires, or electrodes of the battery.

Fig. 108.

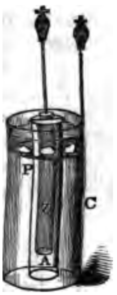


Describe the Voltaic pile. What are its effects? What inconveniences are there in the original form? Describe the trough battery. Describe some of the improvements in the battery.

Some very convenient forms of Voltaic battery have been invented by Dr. Hare. In one of these, the liquid is poured off and on the plates by a quarter revolution of a handle; in others, the trough is made movable, so that it lifts up when all the arrangements are ready, and the plates are immersed.

In almost all the recently improved forms of Voltaic battery, the zinc is amalgamated. This prevents what is termed local action—a waste in which much metal is consumed without adding to the power of the current, and which likewise deteriorates the acid liquid by the accumulation of sulphate of zinc. When amalgamated, all the zinc consumed aids in the current.

Fig. 109.



When it is required to have a current, the intensity of which remains constant for a length of time, Daniell's battery is to be preferred. It consists of a copper cylinder, C, *Fig.* 109, in which a solution of sulphate of copper is poured; within this is a second cylinder, P, of porous earthen-ware, filled with dilute sulphuric acid, A, into which an amalgamated zinc rod, Z, dips. From the copper and zinc, rods project, terminated by binding screws, with which the polar wires may be connected.

Smee's battery is also a very valuable combination: it consists of a plate of platinized silver, or platinized platinum, S, *Fig.* 110, on each side of which are placed parallel plates of amalgamated zinc, Z; these plates are held tightly against a piece of wood, *w*, by means of a clamp, *b*, to which, and also to the silver plate, binding screws, for the purpose of fastening polar wires, are affixed. The whole is suspended, by means of a cross-piece of wood, in a jar containing dilute sulphuric acid.

Fig. 110.

Smee's compound battery, represented in *Fig.* 111, is nothing more than a series of the foregoing simple circles. The figure shows one containing six cells; the position of the platinized silver and zinc plates

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What are the forms introduced by Hare, Daniell, Smee, and Grove respectively?

of one of the pairs is seen at S and Z. It is to be charged with dilute sulphuric acid.

Fig. 111.

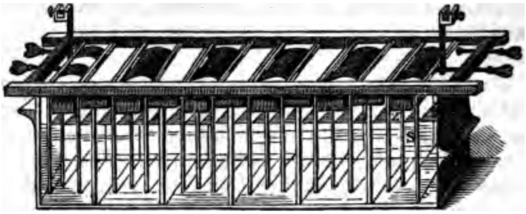


Fig. 112.

Probably the most powerful of all Voltaic combinations is the instrument invented by Mr. Grove. It consists of two metals and two liquids, amalgamated zinc and platina, dilute sulphuric acid and strong nitric acid. A jar, P, *Fig.* 112, three quarters of an inch in diameter, and made of porous or unglazed earthenware, is to be filled with strong nitric acid, N, and in it a slip of platina is placed; this porous earthenware cup is then set in a glass cup, A, nearly three inches in diameter; in this is placed a plate of zinc, Z, one eighth of an inch thick, and of such a size, as respects its other dimensions, that it will readily pass between the porous cup, P, and the glass. In the glass, A is placed dilute sulphuric acid.

In this manner several cups are to be provided, the arrangement being, zinc in contact with dilute sulphuric acid, and platina in contact with strong nitric acid, with a porous cup intervening between. The workman also previously connects each zinc cylinder with the slip of platina, which is in the next cup, by soldering between them a strip of copper.

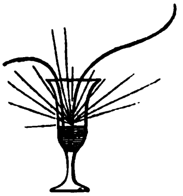
Grove's battery owes its force to the decomposition of water by zinc. But the hydrogen is not evolved from the surface of the platina, as it would be in a single circle; it is here taken up by the nitric acid, which undergoes rapid deoxidation, and therefore, during the use of this battery, volumes of deutoxide of nitrogen are evolved. A battery of fifty cups gives rise to very striking effects; but five or ten are quite sufficient to repeat all the following experiments.

What are the chemical effects taking place in Grove's battery?

On separating the polar wires of such a battery from each other, a brilliant spark passes, and, if the separation be gradual, a flame constantly proceeds from one to the other; the light of which, when the wires are of copper, is of a beautiful green color.

If, on the surface of some quicksilver contained in a glass, *Fig.* 113, we lower a thin piece of steel, or iron wire, connected with one of the poles of the battery, the mercury being kept in contact with the other, the steel takes fire and deflagrates beautifully, emitting bright sparks, and the mercury is rapidly volatilized.

Fig. 113.



When thin metal leaves are made to intervene between the polar wires, they are at once dissipated, the flames they emit being of different colors in the case of different metals.

If a piece of platinum wire is made the channel of communication from one pole to the other, if it does not fuse at once, it becomes incandescent, and remains so as long as the instrument is in activity.

When the polar wires are terminated by pieces of well-burned charcoal, or that variety of carbon which is formed in the interior of gas retorts, the light which passes between them when they are removed from contact is one of the most brilliant that can be obtained by any artificial means. With powerful batteries, the pieces of charcoal may be separated several inches apart without the light ceasing, and then it moves from one pole to the other in an arched form, *Fig.* 114, the convexity of the arc being upward. This form is due to the current of hot air which rises from the ignited space between the poles, and the light may be blown out by the mouth, just in the same manner that we blow out a candle.

Fig. 114.

But, in a scientific point of view, by far the most interesting experiment to be made with the Voltaic battery is the decomposition of water. Through the bottom of a glass vase or dish, at the point *a b*, *Fig.* 115, two platinum wires

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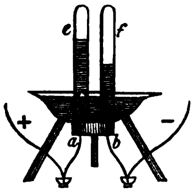
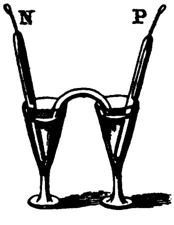
On separating the polar wires of a battery, what phenomenon arises? How may iron wire be deflagrated? What phenomenon is seen during the deflagration of metallic leaves? When a thin platinum wire communicates between the poles, what is the result? How is the arc of light formed, and what are its properties? Describe the process for the decomposition of water.

Fig. 115.



are introduced, water-tight; they pass into the vase, as *a c*, *b d*, parallel to each other, but not touching. Over each of these wires a tube is to be inverted; the tube *e* over *c*, and *f* over *d*, the vase and the tubes being previously filled with water acidulated slightly, to improve its conducting power. Now let the wire *a c* be connected with the positive pole of the Voltaic battery, and *b d* with the negative; bubbles of gas in a torrent arise from their extremities, and pass upward in the tubes, displacing the water. The quantity of gas thus collecting in the two tubes is unequal, and whenever we stop the decomposition there will be found in *f* double the quantity which is in *e*. When a sufficient amount is collected, let the tube *e*, containing the smaller portion of gas, be cautiously removed, preventing any atmospheric air from getting into its interior, by closing it with the finger, and then, turning the tube upside down, let a stick of wood, with a spark of fire on its extremity, be immersed in the gas. In a moment the wood bursts into a flame, proving that this is oxygen gas. Then take the other tube, and allow to pass into it a quantity of atmospheric air equal to the volume of gas it already holds; remove the finger and apply a light, and there is an explosion. But this is the property of hydrogen gas. We therefore conclude that in this experiment water has been decomposed and resolved into its constituent ingredients, oxygen and hydrogen; and, farther, that in water there is, by volume, twice as much hydrogen as there is oxygen gas. The separation of the two is perfect, so much so that the decomposition may be conducted in different vessels. Thus, let N and P be tubes, through the closed upper ends of which platinum wires pass; invert them in glasses of water, with a siphon of large bore connecting them. On making N communicate with the negative, and P with the positive pole, decomposition ensues, hydrogen gas accumulating in N, and oxygen in P.

Fig. 116.



What is the relative proportion of the gases collected? How can it be proved that the less quantity is oxygen and the larger hydrogen? What is the constitution of water by volume?

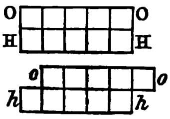
LECTURE XXXI.

THE ELECTRO-CHEMICAL THEORY.—*Theory of the Decomposition of Water.—Decomposition of Metallic and other Salts.—Becquerel's Illustration of the Formation of Minerals.—Davy's Discoveries.—Electro-chemical Theory.—Electrolytes.—Faraday's Theory of definite Action.—The Electrotype.*

THE prominent fact connected with the decomposition of water is the total separation of the constituent elements on the opposite polar wires or electrodes. From the positive wire oxygen alone escapes, and from the negative hydrogen; there is no partial admixture, but the separation is perfect and complete.

Though the polar wires may be separated from each other by a considerable distance, the same result is uniformly obtained, and it is to be remarked that the evolution of gas takes place on the wires alone; no intervening bubbles make their appearance in the intermediate space. The principle on which this is effected may be easily understood, by supposing H H and O O, *Fig.* 117, to represent atoms of hydrogen and oxygen respectively; each pair of them, therefore, represents a particle of water. Now, if we slide the upper row of atoms upon the lower, as shown at *h h*, *o o*, it is obvious that a hydrogen atom will be set free at one extremity of the line, and an oxygen atom at the other, and that, as respects all the intermediate pairs of atoms, though they have changed their places, yet every particle of hydrogen is still associated with a particle of oxygen, constituting, therefore, a particle of water; and it is at the extremes of the line alone that the gases are set free. So in the polar decomposition by the pile, all the liquid intervening between the poles is affected, decompositions and recombinations successively taking place, the hydrogen atoms moving in one

Fig. 117.



Do these polar decompositions effect a total separation of the bodies? In the decomposition of water, do any gas bubbles appear in the intervening space? How is this explained? How is it, if decompositions are going on in the intervening space, that the gases are not there seen?

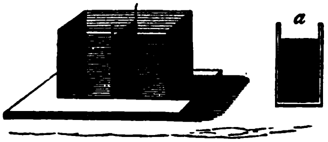
direction, the oxygen in the other, finally to be set free on the surface of the polar wires.

This capital discovery of the decomposition of water by Voltaic electricity was originally made by Nicholson and Carlyle. It is by far the most satisfactory method of demonstrating the constitution of that liquid. After it was made known, any lingering doubts which still remained on the minds of some chemists in relation to the composite nature of water were speedily removed.

In the same manner that water is decomposed by the Voltaic battery, so, also, many metallic and other salts yield to its influence. Thus, if into a jar containing a solution of blue vitriol, the sulphate of copper, two metallic plates are introduced parallel to each other, and one of them brought in connection with the negative and the other with the positive pole of the battery, decomposition of the salt takes place; the sulphate of copper being resolved into its constituents, sulphuric acid and the oxide of copper, and the latter reduced to the condition of metallic copper by hydrogen simultaneously evolved with it, arising from the decomposition of a part of the water. In this manner the copper may be deposited, with a little care, under the form of a tough metallic mass.

If in a cubical glass vessel, *Fig.* 118, divided into two partitions by a diaphragm, *a*, and both partitions filled with a solution of iodide of potassium, mixed with a solution of starch, and the positive and negative wires of the battery introduced, decomposition of the iodide takes place, its iodine being evolved at the positive wire, and giving with the starch a deep blue color, the blue iodide of starch, while the liquid in the other partition remains colorless.

Fig. 118.



M. Becquerel obtained some very beautiful results by the aid of weak but long-continued electric currents, illustrating the probable mode of formation of mineral substances by such currents traversing the crust of the earth. If we take a glass tube bent into the form of a U, and close the bended

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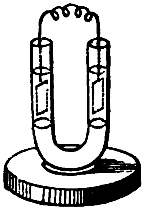
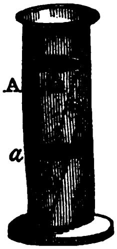
Can metallic salts be in like manner decomposed? Describe the polar decomposition of iodide of potassium. Can decompositions be produced by very feeble Voltaic currents?

Fig. 119.



part with a plug of plaster of Paris, putting in one of the branches a solution of carbonate of soda, and in the other of sulphate of copper, immersing in one of the solutions a zinc plate, and in the other a copper, connected together by a piece of bent wire, the liquids communicate through the porous plug, and crystals of the double carbonate of copper and soda form on the plate immersed in the copper liquid. In the same manner, other compound salts and mineral bodies may be produced.

Fig. 120.



Or if we take a jar, A, and fill it with a solution of nitrate of copper to *a*, and then with dilute nitric acid to B, and immerse in it a slip of copper, C D, presenting equal surfaces to the two liquids, an electric current is generated, the copper is dissolved in the upper solution, and is deposited in crystals at D in the lower.

As in this manner water and various saline bodies undergo decomposition by the action of the pile, it occurred to Sir H. Davy that probably other substances, at that time supposed to be simple, might also be decomposed. He accordingly subjected the alkaline and earthy bodies, then reputed to be elementary, to the influence of a powerful battery, and found that his supposition was verified. On placing a fragment of caustic potash between the poles, it immediately melted; from the positive, oxygen gas escaped in bubbles, and from the negative, small metallic globules, having the appearance of quicksilver, emerged; these were characterized, however, by the singular qualities of an intense affinity for oxygen, so that they would take fire on being touched by water, or even ice, and were so light as to swim upon the surface of that liquid.

The result of Davy's experiments proved that the alkaline substances and all the earths are oxidized bodies, and in most instances oxides of metals.

On these principles, Davy established a division of elementary bodies into electro-positive and electro-negative

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Describe some of the arrangements of M. Becquerel for illustrating the probable mode of formation of minerals. What were the discoveries of Davy respecting the alkaline and earthy bodies?

substances. The former are those which, during a polar decomposition, go to the negative pole, and the latter those that go to the positive. The electro-chemical theory assumes that all bodies have a natural appetency for the assumption of the positive or negative states respectively, and that all the phenomena of chemical combination are merely cases of the operation of the common law of electrical attraction; for between particles in opposite states attraction ought to take place, and when in a compound body, such as water, which consists of particles of negative oxygen and positive hydrogen, the poles of an active Voltaic battery are immersed, they will effect its decomposition, the negative oxygen going to the positive pole, and the positive hydrogen to the negative pole.

Davy's theory thus not only accounts for the decomposing agencies of the battery, but also for all common cases of chemical combination, referring both to the fundamental law of electric attraction. With all its simplicity, it would be very easy to show, however, that it is founded on a groundless assumption, and can not account for a great number of well-known facts.

The Voltaic pile can not decompose all bodies indiscriminately. An electrolyte—for so a decomposable substance is termed—must always be a fluid body. It also appears that all electrolytes must have a binary constitution, or contain one atom of each of their two constituent ingredients.

Mr. Faraday discovered that the action of an electric current in effecting the decomposition of various bodies is perfectly definite: thus, if we make the same current pass through a series of vessels containing water, iodide of potassium, melted chloride of lead, they will all be decomposed, but in very different quantities. If of the water there be decomposed 9 parts, there will be 165 of iodide of potassium, and 139 of chloride of lead; but these numbers represent what will be hereafter given as the atomic weights of the bodies in question. A current which can set free one grain of hydrogen will evolve 108 of silver, 104 of lead, 39 of potassium, 31·6 of copper, &c., these being the atomic weights of those substances respectively.

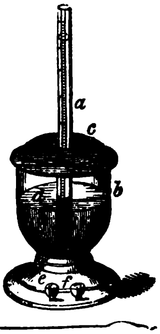
What is meant by the electro-chemical theory? Does this theory also account for chemical combination? To what bodies is the decomposing influence of the Voltaic battery limited? Can substances other than binary compounds be thus decomposed? Explain Faraday's law of the definite action of a Voltaic current.

Fig. 121.

A very beautiful application of electro-chemical decomposition has of late been introduced into the arts. It passes under the name of the electrotype. It consists in the precipitation of metallic copper, gold, silver, platina, &c., on different surfaces, by the aid of a Voltaic current. Thus, suppose it were required to obtain a perfect copy in copper of one of the faces of a medal; let a glass trough, N C, *Fig.* 121, be filled with a solution of the sulphate of copper, and to the negative wire, Z, of a Smee's Voltaic battery, let the medal N be attached, all those portions, except the face designed to be copied, being varnished over, or covered with wax, to protect them from contact with the liquid. To the positive wire, S, let there be attached a mass of copper, C. As soon as the battery is in action, decomposition of the sulphate takes place, metallic copper is precipitated on the face of the medal, copying it with surprising accuracy. This copper is, of course, withdrawn from the sulphate in the solution; but while this is going on, sulphuric acid and oxygen are being evolved on the mass of copper, C. They therefore unite with it; and thus, as fast as copper is precipitated on N by oxydation, new quantities are obtained from C, and the liquid keeps up its strength unimpaired. In the course of a day the medal may be removed. It will be found incrusted with a tough, red coat of copper, which may be readily split off from it. It is a perfect copy of the surface on which the deposition took place, and, in turn, it may be used as a mould for obtaining a great number of casts. Gilding, silver-plating, and platinizing are now performed on the same principles, the electrotype being one of the most beautiful contributions which science has of late given to the arts.

An instrument, the Voltameter, has been invented by Mr. Faraday for measuring quantities of Voltaic electricity. It is represented in *Fig.* 122. It consists of a glass jar,

Fig. 122.



Describe the electrotype.

b, filled to the height *d* with water, and through its cover *c*, a graduated tube, *a*, passes. In the lower part of the tube at *g*, two pieces of platina-foil, which form the terminations of the polar wires of the battery, the current of which is to be measured, are introduced, the connection with those wires being made by the aid of the mercury cups, *e f*. The tube, *a*, having been filled with water, as soon as the current passes decomposition takes place, the gases collecting in the graduated tube, and measuring the amount of the current.

LECTURE XXXII.

OHM'S THEORY OF THE VOLTAIC PILE.—MAGNETISM AND ELECTRO-MAGNETISM.—*Volta's Pile.—Hare's Calorimotor.—Zamboni's Pile.—Ohm's Theory.—Electro-motive Force.—Resistance.—General law for the Force of the Current.—Laws and Phenomena of Magnetism.—Electro-magnetism, Oersted's Discoveries in.—The Galvanometer.—Electric Rotations.—Tangential Force.—Electro-magnets.*

WITH a given amount of metallic surface we can produce Voltaic batteries having different qualities. Thus, if we take a square foot of copper and a square foot of zinc, and place between them a piece of wet cloth, we shall have a battery which can not give shocks, nor effect the decomposition of water, but which will cause a fine metallic wire to become white hot, or even to fuse. If, again, we take a square foot of copper and a square foot of zinc, and cut each into 144 plates, an inch square, and arrange them with similar pieces of cloth as a Voltaic pile, the instrument will give shocks, and decompose water rapidly. From the same quantity of metal two different species of battery may be made; one consisting of a few plates of large surface, or one of a great number of alternations of smaller plates.

Of these varieties of battery, the calorimotor of Dr. Hare is an example of the first. It consists of a series of zinc plates, all connected together, and one of copper, also similarly connected, constituting therefore, in reality, a single pair

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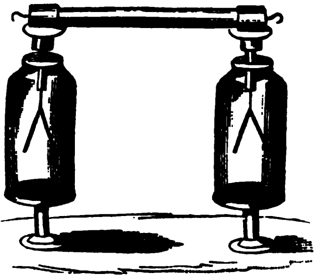
Describe the Voltameter. What are the two principal forms of battery? What does the calorimotor illustrate?

of very large surface. The great amount of heat evolved by this apparatus is its peculiarity.

The electric pile of Zamboni is an example of the other kind. It consists of a series of ten or twenty thousand discs of gilt paper, alternating with similar pieces of very thin zinc foil. These are arranged in a tube, and kept in contact by the pressure of screws at each end. In *Fig.* 123, the pile is laid on a pair of gold leaf electroscopes, both of which diverge, the one being positive and the other negative, the central parts of the pile being neutral. This instrument exhibits no calorific effects; its phenomena are those of electricity of high tension.

Fig. 123.



These, and, indeed, many of the phenomena of the electric current, are clearly accounted for by the aid of Ohm's theory of the Voltaic pile, of which the following is an exposition:

1st. By ELECTRO-MOTIVE FORCE we understand the causes which give rise to the electric current; this, as we have explained in the simple circle, is the oxydation of the zinc. 2d. By RESISTANCE we mean the obstacles which the current has to encounter in the bodies through which it passes.

When we affect the electric current in any portion of its path, either by varying the electro-motive force, or changing the resistances, we simultaneously affect it throughout the whole circuit; so that, in a given space of time, the same quantity of electricity passes through each transverse section of the circuit.

In any Voltaic circle, simple or compound, the force of the current is directly proportional to the sum of all the electromotive forces which are in activity, and inversely proportional to the sum of all the resistances; that is to say, the force of any Voltaic current is equal to the sum of all the

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What does Zamboni's pile illustrate? What is the effect produced by a battery of large plates? What by one of many alternations? What is meant by electro-motive force? In a simple circle, what is its origin? What is meant by resistance? On affecting one part of a current, is the rest affected? What conclusion is drawn from that fact? What is the force of the current equal to?

electro-motive forces, divided by the sum of all the resistances.

The resistance to conduction of a metal wire is directly as its length, and inversely as its section; that is to say, the longer the wire is, the greater its resistance, and the thicker it is, the less its resistance.

If we augment or diminish, in the same proportion, the electro-motive forces and the resistances of a Voltaic circuit, the force of the current will remain the same; if we increase the electro-motive force, the force of the current increases; if we increase the resistance, the force of the current diminishes.

If, in two Voltaic circles of equal force, the same resistance is introduced, the forces of the currents may be enfeebled in very different proportions; for the newly-introduced resistance may, in one of the circles, bear a very great proportion to the resistances already existing, and, in the other, a very insignificant proportion.

The following, therefore, is the general law which determines the force of a Voltaic circuit.

1st. The electro-motive force varies with the number of the elements, the nature of the metals, and of the liquids which constitute each element; but it does not in any manner depend on the dimensions of their parts.

2d. The resistance of each element of a Voltaic circuit is directly proportional to the distance between the plates, as occupied by the liquid, the resistance of the liquid itself, and the length of the polar wire connecting the ends of the circuit; and inversely proportional to the surface of the plates in contact with the liquid, and to the section of the connecting wire.

3d. The force of the current is equal to the electro-motive force divided by the resistance.

From the circumstance that lightning has been repeatedly known to render implements of steel magnetic, and from a general analogy which exists between the phenomena of magnetism and those of electricity, it was long ago believed that these phenomena were due to one common cause; but

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In a wire, what is the law of resistance? How does the force of the current change with changes in the electro-motive force and the resistance? When a new resistance is introduced into two circles, does it follow that both will be affected alike? Give the general law which determines the force of the Voltaic current.

it was not until 1819 that their true relationship was first established by Œrsted.

The phenomena of the magnet itself were discovered more than 2000 years ago. The natural magnet, or loadstone, which is an iron ore, possesses the quality of attracting pieces of iron or steel, but upon almost all other substances it is without action. To hardened steel it communicates its own properties in a permanent manner; but soft iron is only transiently magnetic, and as soon as it is removed from the influence of the magnet it loses its power. Bars of steel which have been magnetized can communicate their activity to other bars; they are, therefore, of constant use in physical investigations, and are of two forms, straight bars and horseshoe magnets.

Fig. 124.

If a magnetic bar have iron filings sifted over it, they collect, as represented in *Fig*. 124, chiefly at the two extremities, *d d*, few of them being found in the middle. If a piece of card-board is laid over a magnet, and the filings dusted on it, they arrange themselves in curves, called magnetic curves; there being in this, as in the former instance, centers of action, P P, toward the extremities of the bars, around which the curves are arranged. The appearance is shown in *Fig*. 125.

Fig. 125.

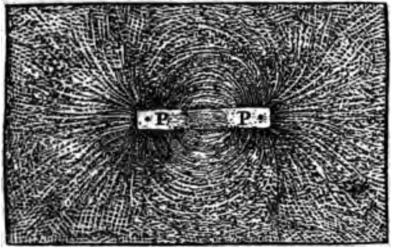
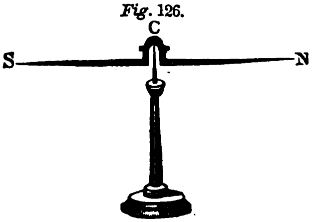


Fig. 126.



A light magnetic bar, S N, so arranged that it can be poised on a pivot, C, with freedom of motion, is a magnetic needle. It was discovered by the Chinese that such a needle, *Fig*. 126, possesses polarity, or points north and

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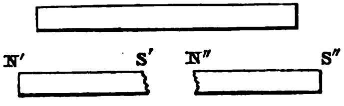
What are the properties of a magnet? What is the difference of its action on iron and steel? What are the forms of artificial magnets? How may the existence of poles be shown by iron filings? Describe a magnetic needle. What is meant by its polarity?

south, a fact of the utmost importance in navigation. When to a needle the poles of a bar are approached, it exhibits attractive and repulsive movements. The law under which these take place is, "Like poles repel, and unlike ones attract;" two north or two south poles repel, but a north and a south attract. Either pole of a magnet is attracted by a piece of unmagnetized soft iron. The intensity of magnetic action is inversely proportional to the square of the distances.

The north and south polarities can not be isolated from one another. If we take a long magnet, N S, *Fig.* 127, and break it in two, we shall not insulate the north polarity in one half and the south in the other, but each of the broken magnets will be perfect in itself, having two poles—one fragment being N′ S′, and the other N″ S″.

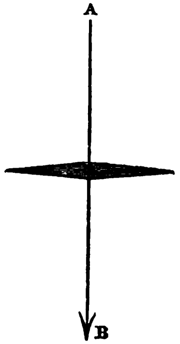
Fig. 127.



Of Electro-Magnetism.

If a magnetic needle be brought into the neighborhood of a wire along which an electric current is passing, the needle is at once disturbed from its position, and tends to set itself at right angles to the wire. Thus, if there be an electric current moving in the direction A B in a wire, and directly over the wire, and parallel to it, there be a suspended needle, as soon as the current passes the needle is deflected from its position, and if the current is sufficiently powerful, comes at right angles to the wire. The direction in which the transverse movement takes place depends on the relative position of the needle and the wire: thus, 1st, if the wire be above the needle and parallel to it, that pole next the negative end of the battery moves westward; 2d, if the wire be beneath the needle, it will move eastward; 3d, if the wire be on

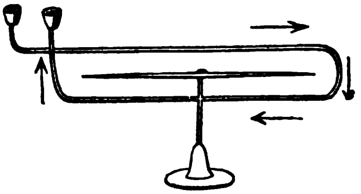
Fig. 128.



What is the law of magnetic attractions and repulsions? How does the intensity of magnetic action vary? What is the direction in which the needle moves in the four positions round the wire?

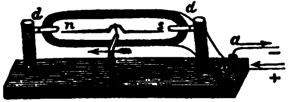
the east side of the needle, the pole is elevated ; 4th, if on the west, it is depressed : in all these various positions, the tendency being to bring the needle at right angles, or transverse to the wire.

Fig. 129.



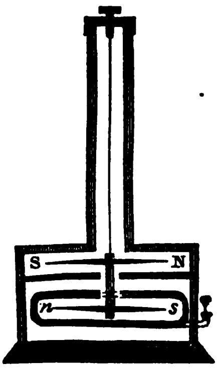
It follows, from these facts, that if a magnetic needle be placed in the interior of a rectangle of wire, *Fig*. 129, through which a current is made to flow, all the portions of the wire conspire to move the needle in the same direction. The effect, therefore, becomes much greater than in the case of a single continuous wire.

Fig. 130.



On the same principle, if, instead of a single turn, the wire is repeatedly coiled upon itself, as at *a d d a*, *Fig*. 130, so as to make a great many turns, the effect upon the included needle, *n s*, is greatly increased, and when the needle is made nearly astatic, that is to say, its tendency to point north nearly destroyed by arranging it upon an axis with another needle similar to it in all respects, but with its poles reversed, as N S, S S, *Fig*. 131, the directive tendency of the one needle neutralizing the other, but both tending to turn in the same direction by the current in the coil of wire, inasmuch as one is within the coil and the other above it, the arrangement forms a most delicate means of discovering and measuring an electric current. It is called a galvanometer.

Fig. 131.



As action and reaction are always equal and contrary, it is obvious that if a conducting wire be movable and the magnet stationary, the latter can be made to impress motions on the former.

What is the effect on a needle in the interior of a rectangle? What is the principle of the galvanometer? On the same principles, can the wire be made to move?

Fig. 132.

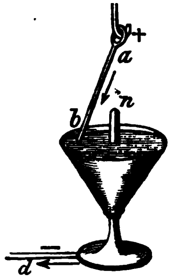
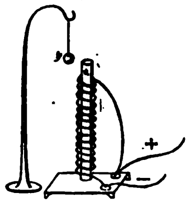
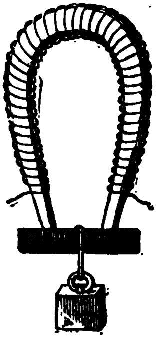


Fig. 133.



Conducting wires can be made to revolve round the poles of a magnet, or the pole of a magnet round a conducting wire; thus, in a glass cup, *Fig.* 132, let a magnet, *n*, be fixed vertically, and the cup filled with mercury; by means of a loop, *a*, let a conducting wire, *b*, be suspended, having perfect freedom of motion. If an electric current is made to pass down this wire through the mercury, and escape by the path *d*, the wire rotates round the pole *n* as long as the current passes. From this and similar experiments, it therefore appears that the force exerted between a conducting wire and a magnet is not a direct attractive or repulsive power, but one continually tending to turn the movable body round the stationary one, deflecting it continually, and acting in a tangential direction. Hence it is sometimes spoken of as a tangential force.

Fig. 134.



If round a bar of soft iron a conducting wire, covered over with silk, be spirally twisted, as in *Fig.* 133, whenever an electric current is passed, the iron becomes intensely magnetic, and loses its magnetism as soon as the current stops. A bar an inch in diameter, bent so as to represent a horseshoe, *Fig.* 134, with a wire covered with silk for the purpose of separating its successive strands from each other, may be made to give rise to very striking results. Professor Henry, by a modification of the conducting wire, succeeded in imparting so intense a degree of magnetism to a piece of soft iron that it could support more than a ton weight. If under one of these ELECTRO-MAGNETS a dishful of small iron nails be held, the moment the current passes, the nails are all attracted, and, while they are held by

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Describe a method of showing the rotation of a wire round the pole of a magnet. What is the nature of the force exerted between a conducting wire and a magnet? Describe the construction and properties of a straight electro-magnet. Describe the horseshoe electro-magnet.

its poles, may be moulded, as it were, by the hand in various shapes, but as soon as the current stops they fall off.

It is upon this principle of producing temporary magnetism by an electric current that Morse's electric telegraph depends.

When different substances are suspended between the polar terminations of one of these horseshoe electro-magnets —in the magnetic field, as it is termed—it is found that some arrange themselves from pole to pole, and others transversely to that position; the former are called magnetic and the latter diamagnetic bodies:

Magnetic Bodies.	*Diamagnetic Bodies.*
Iron,	Bismuth,
Nickel,	Antimony,
Cobalt,	Zinc,
Platinum,	Tin,
Palladium,	Rock crystal,
Titanium,	Wood,
Bottle glass,	Beef,
Crown glass,	Bread,
&c., &c.	&c., &c.

Hot air is more diamagnetic than cold air; a flame, therefore, spreads itself transversely in the magnetic field. In an atmosphere of coal gas, oxygen presents the aspect of a strongly magnetic body.

LECTURE XXXIII.

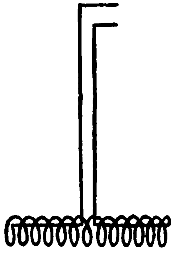
ELECTRO-DYNAMICS — THERMO-ELECTRICITY, &c. — *Ampere's Discovery.—Properties of a Helix.—Nature of the Magnet.—Faraday's Discovery of Magnetic Electricity.—Magnetic Machines.—Faradian Currents.—Thermo-electricity.—Production of Heat and Cold by Electric Currents.—Thermo-electric Pairs.—Peculiarity of these Currents.—Electro-motive Power of Heat.—Melloni's Pile and Thermometer.—Improvements in Thermo-electric Pairs.—Animal Electricity.—Steam Electricity.*

SOON after the relation between electricity and magnetism was established, M. Ampere discovered that there are reactions between electric currents themselves.

What are magnetic and diamagnetic bodies?

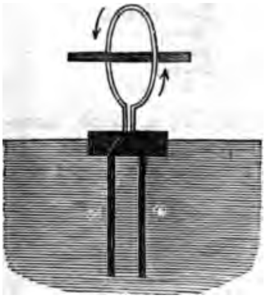
Two electric currents flowing in the same direction attract each other, but two electric currents flowing in opposite directions repel; or, more briefly, "Like currents attract, and unlike ones repel."

Fig. 135.



If a conducting wire be bent in the form of a helix, its terminations returning toward its middle, as shown in *Fig.* 135, it exhibits all the properties of an ordinary magnetized bar; for, as soon as the current passes, it points north and south, and is attracted and repelled by the poles of a magnet just as though it were a magnet itself. A very neat arrangement for illustrating these results is seen in *Fig.* 136. A small simple circle, consisting of a zinc and copper plate, connected together by means of a wire bent so as to form a flat coil, is floated by means of a cork in acidulated water. The current runs round the coil in the direction of the arrows, and the arrangement, obeying the magnetic influence of the earth, turns, with its plane pointing north and south, just as a magnet would do if introduced into the interior of the coil, in the position shown in the figure by the dark line.

Fig. 136.



Ampère infers, from the analogy of these instruments, that the magnet owes its qualities to electric currents circulating in it in a transverse direction. The directive action of the magnetic needle or the electric helix depends on the reaction of electric currents circulating in the earth, due to the unequal heating of its surface by the rays of the sun.

We have seen that an electric current can develop magnetism in a bar of iron or steel; in the former, transient, in the latter, permanent magnetism. Thus, if the iron bar, *n s*, *Fig.* 137, be placed in the axis of a helix of copper wire, along which a current is flowing, the current develops

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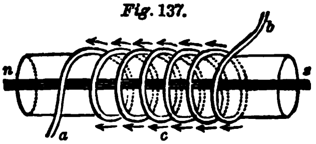
What is the law of reaction between electric currents? Describe the phenomena of the electro-dynamic helix, *Fig.* 135. Describe those of the flat coil. What is Ampere's theory of the nature of the magnet?

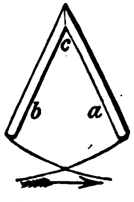
Fig. 137.



magnetism in the bar. It was discovered by Faraday that the converse also holds good, and that a magnet can give rise to an electric current. Thus, in *Fig.* 137, let the terminations *a b* of the helix *c* be brought in contact, and having placed a soft iron bar, *n s*, within it, let the bar be made magnetic by the approach of a strong magnet. As *n s* assumes the magnetic condition, it generates a current, which runs through the helix *c*; and if at this moment the wires *a b* are drawn apart, a bright spark, sometimes called the magnetic spark, passes. It does not come, however, from the magnet itself, but is due to the electric current established in the helix by the disturbing action of the magnet. If between the terminations *a b* a slender wire is placed, it may be made red-hot, or water may be decomposed, or any of the phenomena of a Voltaic battery may be exhibited by the aid of this *magneto-electric* current. On this principle are constructed the magneto-electric machines, of which different forms have of late been so generally introduced for the purpose of the medicinal application of electricity. They all depend essentially on the principle, that if we coil round a piece of soft iron a conducting wire, as often as the iron is magnetized a wave of electricity flows through the wire.

If two conducting wires be placed parallel and near to each other, when an electric current is passed through one of them a wave of electricity flows in the opposite direction through the other; and on the first current stopping, another wave, coinciding with it, passes through the second wire. These momentary currents are all called, from the name of their discoverer, Faradian currents.

Fig. 138.



If we take a bar of antimony, *a*, *Fig.* 138, and one of bismuth, *b*, and having soldered them end to end at *c*, pass a feeble current through them in a direction from the antimony to the bismuth, the temperature of the compound bar rises; but if the current passes in the opposite direction, cold is produced. By

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Can a magnetized bar be made to develop electric currents? What are the properties of these currents? What is the principle of the magneto-electric machine? What is meant by Faradian currents? What is their direction? How may heat and cold be produced by a current in a compound bar?

fixing thermometers into the substance of the bars, these facts may be readily verified, and in the latter case, when water is placed in a depression made for it in the bar, and the reduction of temperature slightly aided. it can be frozen by the electric current.

The same compound bar of bismuth and antimony, having its extremities connected together by a wire, whenever heat is applied to the junction, an electric current sets from the bismuth to the antimony, and when cold is applied, from the antimony to the bismuth. These important facts were discovered by Seebeck in 1822, and the currents have been designated by him thermo-electric currents.

For the production of these thermo-electric effects, two metals are not necessarily required. One end of a thick metallic wire being made red hot and brought in contact with the other, a current instantly passes from the hot to the colder portion, and continues to flow in diminishing quantities until the two ends have reached the same temperature. Or if a metallic ring be made red hot in any limited portion of its circumference, so long as the heat passes with freedom to the right hand and to the left, electric development does not appear; but if we touch with a cold rod the hot portion, abstracting thereby a portion of its heat, a current in an instant runs round it.

It is not alone in metals that these thermo-electric currents can be induced; other solids, and even liquids, may originate them. Among metals associated together, the relation often exhibits singular changes. Copper and iron form a very active couple until their temperature approaches 800° F.; the current then stops, and on continuing the heat, another current is developed, passing in the opposite way. The same takes place with a pair of silver and zinc, at a temperature of 248° F.

Thermo-electric currents generated in metallic bars, experiencing little resistance to conduction, have therefore very little tension; the thinnest stratum of water is a perfect non-conductor to them.

In any thermo-electric couple, the quantity of electricity evolved depends upon the temperature; but, as I have

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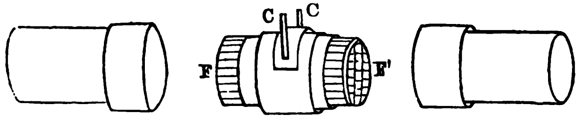
What are thermo-electric currents? Can they be generated by one metal only? Can they originate in other solids besides metals, and in liquids? What is the action of a pair of copper and iron, and silver and zinc? Why have they so little tension?

shown in a memoir on the electro-motive power of heat, inserted in the Philosophical Magazine for June, 1840, it is not directly proportional to it, except through limited ranges of temperature; we can not, therefore, make use of these currents for the determination of temperatures with accuracy, on the hypothesis of the proportionality of the quantities of electricity to the quantities of heat.

By joining a system of bars alternately together, we may reduplicate the effects of a single pair. As might have been predicted on the theory of Ohm, and as I have shown in the memoir just quoted experimentally, where the conducting resistance remains the same, the quantity that passes the circuit is directly proportional to the number of pairs. It is upon this principle that, several years ago, M. Melloni constructed his thermo-electric multiplier, *Fig.* 139.

Fig. 139.



Thirty or forty pairs of minute bars of bismuth and antimony, F F, with their alternate ends soldered together, are arranged in a small space, so that their ends expose an area not exceeding the section of the bulb of a common thermometer, the current that passes from this pile being so conducted, by means of wires, C C, as to deflect a magnetic needle. To the thermo-electric pile a galvanometer is therefore attached, as seen in *Fig.* 140, which represents the whole instrument in section and perspective. A B C is the coil of the multiplier, its terminal wires ending in the connecting cups, F F′. The coil rests on a plate, D E, which can be made to revolve by means of a wheel and screw connected with the button G. An astatic combination of needles is supported by the frame Q M N, by a single silk thread, V L. To protect the instrument from currents of air, it is covered with a glass cylinder, F L, strengthened by brass rings, P S, Y Z; K T is the basis on which the cylinder rests. The angle of deflection of the needle is

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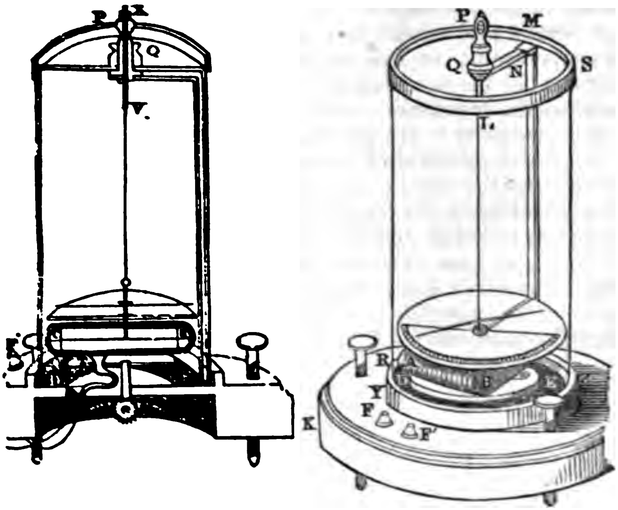
Is the quantity of electricity evolved proportional to the temperature? What is the principle of the thermo-electric multiplier of Melloni? How is it constructed?

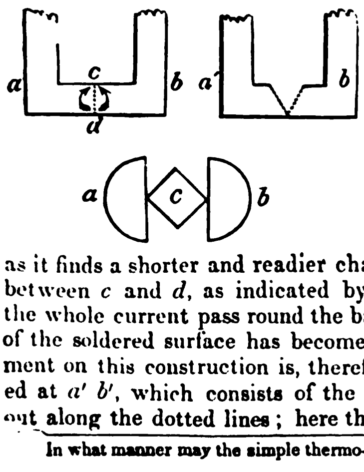
Fig. 140.



taken as the measure of the temperature. Of all thermometers, this is by far the most sensitive.

I have introduced certain improvements in the construction of the thermo-electric element. Let *a*, *Fig*. 141, be a bar of antimony, and *b* a bar of bismuth. Let them be soldered along *c d*, and at *d* let the temperature be raised; a current is immediately excited, but this does not pass round the bars *a b*, inasmuch as it finds a shorter and readier channel through the metals between *c* and *d*, as indicated by the arrows. Nor will the whole current pass round the bars until the temperature of the soldered surface has become uniform. An improvement on this construction is, therefore, such as is represented at *a' b'*, which consists of the former arrangement cut out along the dotted lines; here the whole current, as soon

Fig. 141.



In what manner may the simple thermo-electric pair be improved?

as it exists, is forced to pass along the bars. One of the best forms of a thermo-electric pair is given at $a'' \, b''$, where a'' is a semi-cylindrical bar of antimony and b'' of bismuth, united by the opposite corners of a lozenge-shaped piece of copper, *c*. The heat is to fall on *c*, which becomes hot and cold with promptitude, and determines a current

Besides the various sources of electricity to which I have referred, there are certain animals which possess the power of controlling the equilibrium of the electric fluid in their neighborhood at will, being accommodated for this purpose with a specific nervous apparatus. The torpedo, a fish living in the Mediterranean, and the gymnotus electricus, which is found in some of the fresh water streams of South America, have this property. The shock of the torpedo passes through conducting bodies, but not through non-conductors. A gymnotus which was exhibited in London was found to deflect a magnetic needle powerfully by its discharge. A steel wire was magnetized by it, and iodide of potassium decomposed. In an interrupted metallic circuit a spark was seen, and the induced spark was also obtained by a coil. The current passed from the anterior to the posterior parts of the animal. Mr. Faraday, the author of these experiments, calculates that the quality of electricity passing at each discharge of the fish was equal to that of a Leyden battery containing 3500 square inches charged to its highest degree, and this could be repeated two or three times with scarce a sensible interval of time.

As the electricity which these animals discharge depends on their nervous action, the production of it is attended with a corresponding nervous exhaustion. It is, therefore, not improbable that the converse of these actions holds good, and hereafter it will be found that electricity reacts on the nervous fluid.

It has been shown by Matteucci that in all living animals there is a current of positive electricity from the interior to the exterior of every muscle, and by arranging a series of muscles in such a way as to form a pile, magnetic effects and chemical decomposition may be produced.

In concluding this subject, I may mention a source of

What is animal electricity? By what animals is it exhibited? What effects have been produced by the electricity of the gymnotus? What is the computed quantity of the electricity in each discharge? Why is this electric development attended with a nervous exhaustion? What is the direction of the muscular current?

electricity which of late has excited much attention. When high-pressure steam is allowed to escape from a boiler through a narrow jet, a powerful excitement is produced, and sparks many feet in length may be obtained. The effect appears to be due to the friction of minute drops of water against the tube through which the steam is escaping

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What is the cause of electricity produced by steam?

PART II.

LECTURE XXXIV.

THE NOMENCLATURE.—*The French Nomenclature.—Table of Elementary Bodies.—Nomenclature for Compound Bodies, Acids, Bases, and Salts.*

UNTIL after the discovery of oxygen gas, the nomenclature of chemistry was very loose and complicated. The trivial names which were bestowed on various bodies had frequently little connection with their properties; sometimes they were derived from the name of the discoverer, or sometimes from the place of his residence. Glauber salt takes its designation from the chemist who first brought it into notice, and Epsom salt from a village in England, in which it was at one time made.

It is obvious that such a system of nomenclature, as soon as the number of compound bodies increased, would not only become unmanageable, but, by reason of the impossibility of carrying in the memory such a mass of unconnected terms, offer a very serious impediment to the progress of the science. Lavoisier and his associates, about the close of the last century, constructed a new nomenclature, with a view of avoiding these difficulties. Its principles, with some modifications, are now universally received. The following is a brief exposition of it:

Natural bodies may be divided into two classes, simple and compound; the former are also called elementary. By simple or elementary bodies we mean those which have not as yet been decomposed.

Among simple substances, those which have been known for a long time retain the names by which they are popularly distinguished; thus, gold, iron, copper, &c.; and when

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What was the nature of the nomenclature used by the older chemists When was the system now in use invented? What is meant by simple or elementary bodies? What is the rule for the old simple bodies?

new bodies belonging to this class are discovered, they are to receive a name descriptive of one of their leading properties; thus, chlorine takes its name from its greenish color, and iodine from its purple vapor. It is to be regretted that this rule has often been overlooked.

Some doubt exists as to the exact number of the elementary bodies. It may be estimated at 62, including three metals recently discovered, the titles of which have not yet been completely established.

Of the list of elementary bodies, the metals form by far the larger portion, there being 49 of them; the remaining 13 are commonly spoken of as non-metallic substances. By some authors these are called metalloids, in contra-distinction to the metals, an epithet which, however, is very objectionable.

Table of elementary or simple Substances, with their Symbols and Atomic Weights.

Non-metallic Elements.	Symbols.	At. wts.	Metallic Elements.	Symbols.	At. wts.
Oxygen	O.	8·013	Erbium	E.	——
Hydrogen	H.	1·000	Terbium	Tr.	——
Nitrogen	N.	14·19	Manganese	Mn.	27·72
Sulphur	S.	16·12	Iron	Fe.	27·18
Phosphorus	P.	32·00	Cobalt	Co.	29·57
Carbon	C.	6·04	Nickel	Ni.	29·62
Chlorine	Cl.	35·47	Zinc	Zn.	32·31
Bromine	Br.	78·39	Cadmium	Cd.	55·83
Iodine	I.	126·57	Lead	Pb.	103·73
Fluorine	F.	18·74	Tin	Sn.	58·92
Boron	B.	10·91	Bismuth	Bi.	71·07
Silicon	Si.	22·22	Copper	Cu.	31·71
Selenium	Se.	39·63	Uranium	U.	217·20
			Mercury	Hg.	202·87
Metallic Elements.			Silver	Ag.	108·31
Potassium	K.	39·26	Palladium	Pd.	53·36
Sodium	Na.	23·31	Rhodium	R.	52·20
Lithium	L.	6·44	Iridium	Ir.	98·84
Barium	Ba.	68·66	Platinum	Pt.	98·84
Strontium	Sr.	43·85	Gold	Au.	199·2
Calcium	Ca.	20·52	Osmium	Os.	99·72
Magnesium	Mg.	12·89	Titanium	Ti.	24·33
Aluminum	Al.	13·72	Tantalum	Ta.	184·90
Glucinum	G.	26·54	Tellurium	Te.	64·25
Yttrium	Y.	32·25	Tungsten	W.	99·70
Zirconium	Z.	33·67	Molybdenum	Mo.	47·96
Thorium	Th.	59·83	Vanadium	V.	68·66
Cerium	Ce.	46·05	Chromium	Cr.	28·19
Lanthanum	La.	——	Antimony	Sb.	64·62
Didymium	D.	——	Arsenic	As.	37·67

What is the rule for the simple bodies newly discovered? What is the number of the elementary bodies? Of these, to what class do the greater part belong? What are the symbols for the elementary bodies? What are heir atomic weights?

To this table the names of four metals, recently discovered and but little known, might be added. They are Niobium (Nb.), Norium (No.), Pelopium (Pe.), and Ruthenium (Ru.).

Compound bodies may, for the most part, be divided into three groups: acids, bases, and salts. By an acid we mean a body having a sour taste, reddening vegetable blue colors, and neutralizing alkalies; by a base, a body which restores to blue the color reddened by an acid, and possessing the quality of neutralizing the properties of an acid; by a salt, the body arising from the union of an acid and a base These definitions, however, are to be received with considerable limitation.

The nomenclature for acid substances is best seen from an example. Thus sulphur and oxygen unite to form an acid: it is called sulphuric acid; the termination in *ic* being expressive of that fact. But very frequently two substances will form more than one acid, by uniting in different proportions; in this case the termination in *ous* is used; thus we have sulphurous acid, so called because it contains less oxygen than sulphuric. The prefix "hypo" is also used, as in hyposulphurous and hyposulphuric acids: it indicates acids containing *less* oxygen than sulphurous and sulphuric acids. The prefix "hyper" is used in the same way; thus, hyperchloric acid, an acid containing *more* oxygen than chloric acid.

With respect to bases, the generic termination is in *ide*. If oxygen and lead unite, we have oxide of lead, and in the same manner we have chlorides, bromides, iodides, and fluorides. And if these elements form compounds in more proportions than one, we indicate their proportion by the Greek numerals, protos, deuteros, tritos: thus we have protoxides, deutoxides, tritoxides; the protoxide of lead contains one atom of oxygen and one of lead, the deutochloride of mercury two atoms of chlorine and one of mercury, &c. In the same manner, the prefixes sub, sesqui, and per are used; thus, a suboxide contains the lowest proportion of oxygen, a peroxide the highest proportion, and a sesquioxide inter-

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Into what groups may compound bodies be divided? What is the definition of an acid? What is a base? What is a salt? What do the terminations *ic* and *ous* indicate? What is the meaning of the prefixes *hypo* and *hyper?* What does the termination *ide* signify? What the prefixes *protos*, *deuteros*, and *tritos*, *sub*, *sesqui*, and *per?*

venes between a protoxide and a deutoxide, its oxygen being in the proportion of one atom and a half.

By an alloy, we mean the substance arising from the union of two metals; thus copper and zinc unite to form brass, which is an alloy. If one of the metals is mercury the compound is called an amalgam. And when sulphur, phosphorus, carbon, and selenium unite with metals, or with each other, the termination *uret* is used; thus we have sulphurets, phosphurets, carburets, &c.

With respect to the nomenclature for salts, the terminations *ate* and *ite* are used to indicate acids in *ic* and *ous* respectively. The sulphate of potash contains sulphuric acid, and the sulphite of potash sulphurous acid. And as we have already seen that different oxides arise by the union of oxygen in different proportions, and these bodies frequently give rise to different series of salts, the operation of the nomenclature may be readily traced: thus, the protosulphate of iron is the sulphate of the protoxide of iron, but the persulphate of iron is a sulphate of the peroxide, and the deutosulphate of platinum a sulphate of the deutoxide of platinum. When the relative quantity of the acid and base varies, Latin numerals are employed; thus the bisulphate of potash contains two atoms of sulphuric acid and one of potash.

Salts are said to be neutral if neither their acid nor base be in excess. If the acid predominates, it is an acid, or super-salt; if the base, it is a basic, or sub-salt.

LECTURE XXXV.

THE SYMBOLS—*Failure of the Nomenclature in the Case of Complex Compounds.—Failure in Difference of Grouping.—Symbols for elementary Bodies.—Expressions for several Atoms.—Use of the Plus Sign.—Expressions for Grouping.*

So long as the constitution of compound bodies is simple, there is no difficulty in applying the nomenclature, or

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What is an alloy and an amalgam? When is the termination *uret* employed? What do the terminations *ate* and *ite* indicate? What is the nomenclature for the salts? What is a neutral salt? What is an acid, or super-salt? What is a basic, or sub salt?

in recognizing from the name of the compound the nature and proportions of its constituents. Thus, protoxide of hydrogen clearly indicates a body in which one atom of oxygen is united with one of hydrogen, bisulphate of potash a body composed of two atoms of sulphuric acid and one of potash, and even in more complicated cases, such as the sulphato-tricarbonate of lead, &c., the same principle will serve as a guide.

But when compound bodies consist of a great number of atoms, the nomenclature ceases to be of any service. Thus, starch is composed of twelve atoms of carbon, ten of hydrogen, and ten of oxygen. Fibrin is composed of forty-eight atoms of carbon, thirty-six of hydrogen, fourteen of oxygen, six of nitrogen, with minute but essential quantities of sulphur and phosphorus. On the principles of the nomenclature, it would be difficult to give to the first a technical name, and in the case of the latter impossible.

The peculiarity of organic compounds is, that they contain but few of the elementary bodies, being chiefly made up of carbon, hydrogen, oxygen, and nitrogen; but these, as in the case of fibrin, unite in a very complicated way, very often hundreds of atoms being involved. The nomenclature is therefore inapplicable to organic chemistry.

There is also another very serious difficulty in its way. It has been discovered that compounds may consist of the same elements, united in precisely the same proportions, so that when they are analyzed they yield precisely the same results, and yet they may, in reality, be very different substances. Identity in composition is no proof of the sameness of bodies. Thus we may have the same elements uniting together in the same proportion, and yielding a solid, a liquid, or a gas indifferently. This result may depend on several causes, as will be presently explained; but among these causes I may here specify what is termed by chemists "Grouping." Thus, suppose four elementary bodies, A B C D, unite together, there is obviously a series of compounds which may arise by permuting or grouping them differently, as in the following example:

Under what circumstances does the nomenclature apply, and when does it fail? What is the peculiarity of organic compounds? Why is the nomenclature inapplicable to organic chemistry? Is identity of composition any proof of the identity of bodies? What is meant by grouping?

$$\begin{array}{llll} (1) & A + B + C + D. & & \\ (2) & A\,C & + B\,D. & \\ (3) & A\,D & + C\,B. & \\ & \&c. & \&c. & \end{array}$$

The method of symbols, which is designed to meet these difficulties, and is, in reality, an appendix and improvement upon the nomenclature, was originally introduced by Berzelius; but the form which is now most commonly adopted is that of Liebig and Poggendorff. The advantages which have been found to accrue from it are so great, that it is now introduced into every part of chemistry, so that it is impossible to read a modern work on this science without having previously mastered the symbols.

The student should not be discouraged at the mathematical appearance of chemical formulæ. He will find, by a little attention, that they are founded upon the simplest principles, and involve merely the arithmetical operations of addition and multiplication. The following is a brief exposition of their nature:

For the symbol of an elementary substance we take the first letter of its Latin name, as is shown in the table given in the last lecture. Those symbols should be committed to memory. But as it happens that several substances sometimes have the same initial letter, to distinguish between them we add a second small letter. Thus, carbon has for its symbol *C.;* chlorine, *Cl.;* copper (cuprum), *Cu.;* cadmium, *Cd.*, &c. It may be observed that in the case of recent Latin names the German synonym is always used; thus, potassium is called kalium in Germany, and has for its symbol *K.;* sodium is called natrium, and has for its symbol *Na.*, &c.

But a symbolic letter standing alone not merely represents a substance; it farther represents *one* atom of it; thus, *C* means one atom of carbon, and *O* one atom of oxygen.

If we wish to indicate that more than one atom is present, we affix an appropriate figure, as in the following examples: $C_{12} \,.\, H_{10} \,.\, O_{10}$. Thus, nitric acid is composed of one atom of nitrogen united to five of oxygen, and we write it NO_5.

Give an example of grouping. What are the symbols for elementary bodies? When two bodies begin with the same letter, how are the symbols arranged? What does a single symbol standing alone represent? How are more atoms than one represented?

When a compound, formed of several compounds, is to be represented, we make use of an intervening comma; thus, strong oil of vitriol is composed of one atom of sulphur and three of oxygen, united with one atom of water, which is composed of one atom of oxygen and one of hydrogen, and we write it SO_3, HO.

If we desire to indicate that compounds are united with a feeble affinity, we make use of the sign +; thus, the composition of sulphuric acid may be written SO_3, or SO_2+O, the latter formula implying that one of the atoms of oxygen is held by a feebler affinity than the other two.

When a large figure, or coefficient is placed on the same line as the symbol, and to the left of it, it multiplies that symbol as far as the first comma or + sign; or, if the formula be placed in a parenthesis, it multiplies every letter under the parenthesis; thus, $2SO_3, KO, HO$, or $2SO_3+KO+HO$ mean two atoms of sulphuric acid united with one of potash and one of water, forming the bisulphate of potash; but $2(SO_3, KO, HO.)$ would represent two atoms of a salt composed of one of sulphuric acid, one of potash, and one of water, the figure here multiplying all under the parenthesis.

The advantages which arise from the use of these simple rules are very great; we can, even with the most complex bodies, not only express their composition, but also the molecular arrangement, or grouping of their atoms; we can follow them through the most intricate changes, and without difficulty trace out their metamorphoses. For example, analysis shows that alcohol is composed of

$$C_4, H_6, O_2,$$

but many facts in its history lead us to know that its molecular constitution is

$$(C_4H_5)O+HO;$$

that is to say, it contains a compound radical C_4H_5, to which the name of ethyl has been given, and this fact being understood, we see at once that upon the principles of the nomenclature the true name for alcohol is the hydrated oxide of ethyl; moreover, alcohol is derived by processes of fermentation from sugar. The constitution of dry grape sugar is

$$C_{12}, H_{12}, O_{12}.$$

How is the comma employed? What is the use of the sign *plus*? How far does a coefficient multiply? What are the advantages arising from the symbols? Give an example in the case of alcohol.

This complex atom, under the influence of active yeast, is split into

$$2(C_4 H_6 O_2) \ldots\ldots 4(CO_2),$$

that is to say, into two atoms of alcohol and four of carbonic acid gas; and, accordingly, we find, during fermentation, that the sugar disappears, alcohol forming in the liquid, and carbonic acid gas escapes.

The student should accustom himself to the translation of the nomenclature into symbols, and symbols into the nomenclature, in cases where it is possible, for it is absolutely essential that he should be perfectly familiar with the process.

LECTURE XXXVI.

THE LAWS OF COMBINATION.—*Law of Fixed Proportions.—Numerical Law.—Multiple Law.—Modes of expressing Composition.—Proportions, Equivalents, and Atomic Weights.—Relation between Combining Volumes and Atomic Weights.—Table of Specific Gravities and Atomic Weights.*

IT has been shown, in the first and second lectures, that material substances possess an atomic constitution, and all the phenomena of chemistry bear out this conclusion. It follows, therefore, when substances combine with each other and give rise to new products, the union takes place by the atoms of the one associating themselves with the atoms of the other, and as these atoms possess weight and other properties which are specific, there are certain circumstances, easily foreseen, which must attend such combinations.

1st. The constitution of a compound body must always be fixed and invariable. This arises from the fact of the unchangeability of the properties of atoms; one atom of water will always be composed of one atom of oxygen and one of hydrogen; one atom of carbonate of lime will always consist of one atom of carbonic acid and one of lime. Or, more generally, if a good analysis of water has shown that nine grains of that substance contain eight grains of oxygen

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In what manner does the combination of bodies take place? What is meant by the law of fixed proportions?

and one of hydrogen, every subsequent analysis will correspond therewith.

2d. The proportions in which bodies are disposed to unite with each other can always be represented by certain numbers; these numbers being, in fact, the relative weights of their atoms. Thus water is composed of an atom of oxygen and one of hydrogen, and inasmuch as the oxygen atom is eight times heavier than that of hydrogen, it necessarily follows that in every nine parts of water we shall have eight of oxygen and one of hydrogen. These numbers are therefore spoken of as the combining proportions or equivalents of the substances to which they are attached. If, farther, we examine, when oxygen and sulphur unite, what are the relative quantities, we shall find that eight parts of oxygen combine with sixteen of sulphur, forming hyposulphurous acid. And if sulphur and hydrogen unite, it will be found that sixteen of sulphur combine with one of hydrogen. In this manner, by examining the various elementary bodies, we find that certain numbers are expressive of the proportions in which they are disposed to unite, and these numbers represent the relative weight of their atoms; thus, if 1 be taken as the atomic weight of hydrogen, that of oxygen is 8, that of sulphur 16, &c.; the atomic weights of the elementary bodies have been given in Lecture XXXIV.

3d. If two substances unite with each other in more proportions than one, those proportions bear a very simple arithmetical relation to one another; thus, 14 grains of nitrogen will successfully unite with 8, 16, 24, 32, 40 grains of oxygen, forming successively the protoxide of nitrogen, the deutoxide, hyponitrous acid, nitrous acid, and nitric acid. And when the numbers expressing the amount of oxygen are examined, it is seen that they are in the second twice, in the third thrice, in the fourth four times, and in the fifth five times the amount of the first; they are, therefore, simple multiples of it. The reason of this is plain when we write the constitution of these bodies in symbols; they are successively,

$$NO \ldots NO_2 \ldots NO_3 \ldots NO_4 \ldots NO_5;$$

What by the numerical law? Give an example in each case. What do the numbers represent? Give examples of these numbers. What is meant by the multiple law? Give an example of it in the case of the compounds of nitrogen and oxygen.

and if one atom of oxygen weighs 8, two must weigh 16, three 24, four 32, &c.; the multiple law, therefore, is a necessary consequence of the combination of atoms.

Observation has shown that there are two series according to which bodies may unite with each other.

(1.) 1 atom of A may unite with 1, 2, 3, 4, 5, &c., atoms of B.
(2.) 1 atom of A may unite with $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, &c., atoms of B.

But as an atom is indivisible, there can be no such thing as a half atom; consequently the second series becomes,

(3.) 2 atoms of A may unite with 1, 2, 3, 4, 5, &c., atoms of B.

The three foregoing laws are known under the name of the laws of combination; they are the law of definite proportions, the law of numbers, and the multiple law.

There are three ways in which the composition of a substance may frequently be expressed: 1, by atom; 2, by weight; 3, by volume. Thus, the constitution of water, by atom, is one of oxygen to one of hydrogen; by weight, it is one of hydrogen to eight of oxygen; and by volume, two of hydrogen to one of oxygen. These different modes of expression involve nothing contradictory; they are all reconciled by the statement that the atom of oxygen is eight times as heavy as that of hydrogen, but only half the size.

By some authors the terms combining proportion and equivalent are used; they have the same signification as atomic weight. And as we know nothing of the absolute weight of atoms, but only their relative proportions to each other, we may select any substance with which to compare all the rest, and make it our unit or term of comparison. In this book hydrogen is employed for this purpose, and its atomic weight is marked 1; on the Continent of Europe oxygen is selected, and marked 100. It is obvious that this does not affect the relationship of the numbers, for it is the same thing whether we state the atomic weights of hydrogen and oxygen as 1 to 8, or as $12\frac{1}{2}$ to 100.

Combinations may take place in two different ways: 1st, in definite proportions; 2d, in indefinite proportions. It is to the former that all the foregoing observations and laws

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What are the two series in which bodies may unite? In what ways may the composition of a body be frequently expressed? How is the apparent contradiction of these statements reconciled? What do proportion and equivalent signify? What is the substance with which all others are compared for their atomic weights in this book? What other standards might be employed? What are the two modes of combination?

apply. One grain of hydrogen will not unite with nine or seven grains of oxygen, but only with eight. But one drop of spirits of wine may combine with one of water, or with a pint, or a quart, or ten gallons. This is what is understood by union in indefinite proportions.

When two gaseous bodies unite, their combining proportions bear a simple relation to each other; one volume of hydrogen unites with one of chlorine, and produces two volumes of hydrochloric acid. And in the case of the five compounds of nitrogen just referred to, two volumes of that gas combine successfully with 1, 2, 3, 4, 5 of oxygen.

A relation, therefore, exists between the combining volume and the atomic weight of gaseous bodies. If the weight of a given volume of oxygen be called 100·0, that of an equal volume of hydrogen will be 6·25, these numbers representing, of course, the specific gravity of the two gases. The proportion in which they unite is one volume of oxygen to two of hydrogen to form water; the relative weights of these quantities, therefore, would be 100·0 to 6·25 × 2, that is, 100·0 to 12·50; but these numbers are the atomic weights of the bodies respectively. From such considerations, it was at one time supposed that, in the case of all gases, the specific gravities would correspond to the atomic weights. Experience has, however, shown that this is not the case, as is seen in the following table:

Gas, or Vapor.	Specific Gravities.		Chemical Equivalents.	
	Air = 1.	Hydrogen = 1.	By Volume.	By Weight.
Hydrogen	0·0690	1·00	100·	1·00
Nitrogen	0·9727	14·12	100·	14·15
Carbon (hypothetical)	0·4213	6·12	100·	6·12
Chlorine	2·4700	35·84	100·	35·42
Iodine	8·7011	126·30	100·	126·30
Bromine	5·3930	78·40	100·	78·40
Mercury	6·9690	101·00	200·	202·00
Oxygen	1·1025	16·00	50·	8·00
Phosphorus	4·3273	62·8	25·	15·70
Arsenic	10·3620	150·8	25·	37·7
Sulphur	6·6480	96·48	16·66	16·10

From this it is seen, that if the combining volume of hydrogen, nitrogen, or chlorine be taken as unity, that of oxygen is one half, of vapor of phosphorus one fourth, and of vapor of sulphur one sixth.

What relation is observed when gases combine by volume? What is the relation between specific gravities and atomic weights?

LECTURE XXXVII.

CONSTITUTION OF BODIES.—*Calculation of Specific Gravities.*—*Crystallization.*—*Systems of Crystals.*—*Dimorphism.*—*Isomorphism.*—*Isomorphous Groups.*—*Isomerism.*—*Metameric and Polymeric Bodies.*—*Allotropic States of Bodies.*

ON the principles which have just been developed, we can often calculate the specific gravity of a compound gas with more accuracy than it can be determined experimentally. Thus, hydrochloric acid, which consists of equal volumes of chlorine and hydrogen united, without condensation, must have a specific gravity of 1·2695, because the specific gravity of hydrogen being 0·0690, and that of chlorine 2·4700, the sum of which, 2·5390, is the weight of two volumes of hydrochloric acid, and, therefore, if we divide by 2, the quotient, 1·2695, is equal to the weight of one volume; or, in other words, the specific gravity of the compound gas.

Sometimes, also, we can determine the specific gravity of a vapor by calculation when it is impossible to do so experimentally. Assuming that one volume of carbonic acid gas contains one volume of oxygen and one of carbon vapor; we have,

Specific gravity of carbonic acid . . .	1·5238
" " oxygen	1·1025
" " carbon vapor . . .	·4213

The hypothetical specific gravity of the vapor of carbon is therefore ·4213.

The rule for the calculation of specific gravities, on the foregoing principles, is, "Multiply the specific gravities of the simple gases or vapors respectively by the volumes in which they combine, add those products together, and divide the sum by the number of volumes of the compound gas produced."

How may the specific gravity of a compound gas be determined? How is the hypothetical specific gravity of the vapor of carbon determined? What is the rule for the calculation of the specific gravities of compound gases from those of their constituents?

It frequently happens that substances assuming the solid form, from the liquid or vaporous states, take on a geometrical figure, being terminated by sharp edges and solid angles; under such circumstances, they are said to crystallize. Thus, common salt will crystallize in cubes, and nitrate of potash in six-sided prisms.

The various geometrical forms which crystals can thus assume may be divided into six classes, or systems:

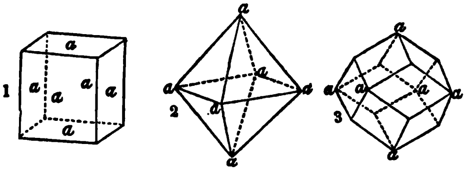
(1.) The Regular system.
(2.) The Rhombohedral system.
(3.) The Square Prismatic system.
(4.) The Right Prismatic system.
(5.) The Oblique Prismatic system.
(6.) The Doubly Oblique Prismatic system.

This division is founded on the relations of certain lines, or axes, which may be supposed to be drawn through the centre of the crystal round which its parts are symmetrically arranged.

THE REGULAR SYSTEM.

This has three equal axes at right angles to each other.

Fig. 142.



The letters *a a* show the direction of the axes. The figure (*Fig.* 142) represents, 1. *The cube;* 2. *Regular octahedron;* and, 3. *Rhombic dodecahedron.*

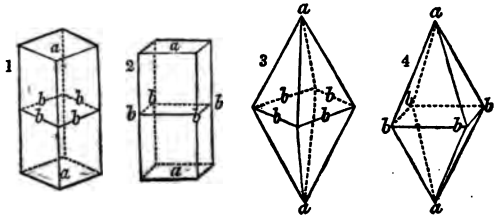
THE SQUARE PRISMATIC SYSTEM.

This has three axes, two of which are equal, and the third of a different length.

a a is the principal axis; *b b* the secondary one. In the figure (*Fig.* 143), 1 is a *right square prism*, with the axes on the centre of the sides, *b b;* 2 is a *right square prism*, with the axes in the edges; 3 and 4 corresponding *right square octahedrons.*

What are the six systems of crystallization? Upon what fact is this division founded? In the regular system, what is the relation of the axes? In the square prismatic system, what is their relation?

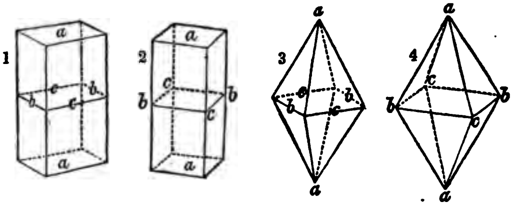
Fig. 143.



THE RIGHT PRISMATIC SYSTEM

has three axes, *a a*, *b b*, *c c*, of unequal lengths, at right angles to each other.

Fig. 144.

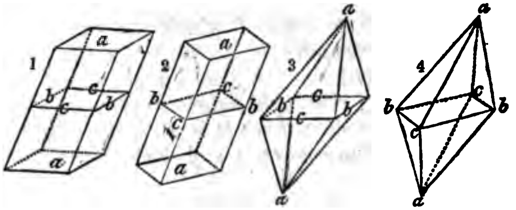


In the figure (*Fig*. 144), 1 is a *right rectangular prism;* 2. *Right rhombic prism;* 3. *Right rectangular based octahedron;* 4. *Right rhombic based octahedron.*

THE OBLIQUE PRISMATIC SYSTEM

has three axes, which may be unequal; two are placed at right angles to each other, and the third is oblique to one and perpendicular to the other.

Fig. 145.



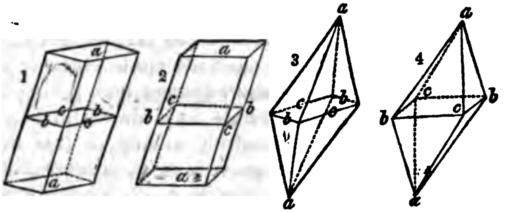
What is it in the right prismatic? In the oblique and double oblique prismatic systems, what is it?

In the figure (*Fig.* 145), 1 is an *oblique rectangular prism;* 2. *Oblique rhombic prism;* 3. *Oblique rectangular based octahedron;* 4. *Oblique rhombic based octahedron.*

THE DOUBLY OBLIQUE PRISMATIC SYSTEM

has three axes, which may be all unequal and all oblique.

Fig. 146.

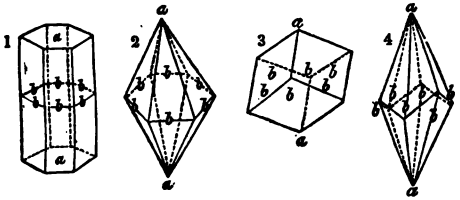


In the figure (*Fig.* 146), 1 and 2 are *doubly oblique prisms;* and 3 and 4 *doubly oblique octahedrons.*

THE RHOMBOHEDRAL SYSTEM

has four axes, three of which are equal in the same plane, and inclined at angles of 60°; the fourth, which is the principal axis, is perpendicular to all.

Fig. 147.

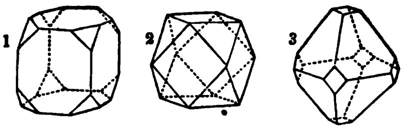


In the figure (*Fig.* 147), 1 is the *regular six-sided prism;* 2, the *dodecahedron;* 3. *Rhombohedron;* 4, another *dodecahedron.*

It often happens, owing to a change in the deposit of new matter on a crystal while forming, that other figures than the proper one are produced; thus, the cube may pass into the octahedron, as shown in *Fig.* 148.

How many axes are in the rhombohedral system, and what is their relation? In what manner may crystals of one form pass into those of another, as the cube into the octahedron?

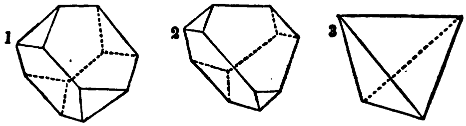
Fig. 148.



The effect may, perhaps, be better conceived by imagining the solid angle of the cube 1 to be cut off by planes equally inclined to the constituent faces. 2 represents an increased removal of the same kind; 3 one still farther advanced.

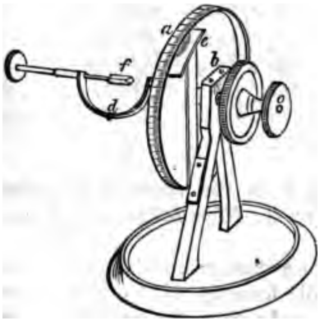
Sometimes it happens that each alternate plane of a crystal grows at the expense of the adjacent one, giving rise to *hemihedral*, or half-sided crystals, as is shown in *Fig*. 149, which represents the tetrahedron, arising in this manner from the octahedron by the growth of each alternate face. 1. The octahedron partially modified; 2. The change farther advanced; 3. The tetrahedron completed.

Fig. 149.



The angles of crystals are measured by goniometers, of which there are several kinds; as the common goniometer, and Wollaston's reflecting goniometer. This instrument is represented in *Fig*. 150. The crystal to be measured, *f*, is fixed upon a movable support, *d*, which is in connection with the button-headed axis of the goniometer, *o*, which passes through a larger axis in the upright, *b*. *a* is a divided circle, and *e* its vernier, which is fixed immovably on the upright, *b*.

Fig. 150.



The edge of the crystal, which is formed by the two faces

What are hemihedral crystals, and how are they produced? Describe the use of the reflecting goniometer.

whose inclination is to be measured, is to be set parallel to the axis of the instrument; and having, by means of the button, *o*, turned the crystal until some definite object, such as the bar of a window, is seen distinctly reflected from it, the larger milled head is turned, and with it the divided circle and crystal, until the same object is again seen by reflection from the second face. The angle through which the great circle has moved, subtracted from 180°, gives the angle included between the two crystalline faces, or their inclination to each other.

As a general rule, the same substance, crystallizing under the same circumstances, will produce crystals belonging to the same system. Cases, however, are known in which the same substance belongs to different systems. Thus, sulphur will crystallize in rhombic prisms, and also rhombic octahedrons. By dimorphous bodies we therefore mean substances which will afford crystals belonging to two different systems.

Dimorphism is frequently connected with the temperature at which the crystals were produced. Thus, carbonate of lime, at ordinary temperatures, yields rhombohedrons, but at the boiling point of water right rhombic prisms; and with this difference of form a difference of chemical qualities may occur; the bisulphuret of iron, for example, crystallizes in cubes, which remain unacted upon by water or air; but in its right rhombic form it undergoes rapid oxydation in moist air, producing sulphate of iron. Commonly one of the forms of a dimorphous body is less stable than the other, and if the transition takes place abruptly, it is sometimes attended by a flash of light.

It was discovered by Mitscherlich, that when different compound bodies assume the same form, we are often able to trace a remarkable analogy in their chemical composition. Thus, the chloride of sodium, the iodide of potassium, the fluoride of calcium, &c., crystallize in the first system. These substances are all constituted upon a common type, in which we have one atom of a metal united to one atom of an electro-negative radical; or, taking *M* as the general symbol for the metals, and *R* for the

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What is meant by dimorphous bodies? What effect has temperature on he formation of crystals? Is dimorphism connected with peculiarities in he chemical qualities of bodies? What relation is there in the form and mposition of iodide of potassium and chloride of sodium?

electro-negative radicals, the class is constituted upon the type

$$M, R,$$

and therefore includes such bodies as

$$KCl\,..\,NaCl\,..\,KBr\,..\,KF\,..\,CaF.\,AmCl\,...\,\&c.$$

Such substances are called isomorphous bodies, and the designations, isomorphous elements, isomorphous groups, are used, being derived from ιαος, equal, μορφη, form.

Let us take a second more complicated case. The formula for common alum, the sulphate of alumina and potash, is,

$$KO,\ SO_3 + Al_2\,O_3,\ 3SO_3 + 24HO.$$

Ammonia alum is $AmO,\ SO_3 + Al_2\,O_3,\ 3SO_3 + 24HO.$
Chrome alum is $KO,\ SO_3 + Cr_2\,O_3,\ 3SO_3 + 24HO.$
Iron alum is $KO,\ SO_3 + Fe_2\,O_3,\ 3SO_3 + 24HO.$

And in the same way an extensive family of alums may be formed by the substitution of a limited number of various other bodies comprised in the general formula,

$$mO,\ SO_3 + M_2\,O_3,\ 3SO_3 + 24HO,$$

in which *m* represents any metal belonging to the potassium group, and *M* any one belonging to the aluminum group.

All these alums crystallize with the same form, and such illustrations afford us reason to believe that that similarity of form is due, in a great measure, to the *grouping* or *arrangement* of the constituent atoms; *that in a compound molecule the substances which can replace one another without giving rise to a change of external form must have certain relationships to each other. We call them, therefore, isomorphous.* The following ten groups have been established:

1.	
Silver	Ag
Gold.	Au
2.	
Arsenious Acid (in its unusual form) . . .	$As_2\,O_3$
Sesquioxide of Antimony	$Sb_2\,O_3$
3.	
Alumina	$Al_2\,O_3$
Sesquioxide of Iron .	$Fe_2\,O_3$
Sesquioxide of Chromium	$Cr_2\,O_3$
Sesquioxide of Manganese	$Mn_2\,O_3$
4.	
Phosphoric Acid . .	$P_2\,O_5$
Arsenic Acid	$As_2\,O_5$
5.	
Sulphuric Acid . . .	$S\,O_3$
Selenic Acid	$Se\,O_3$
Chromic Acid . . .	$Cr\,O_3$
Manganic Acid . . .	$Mn\,O_3$

Why are they called isomorphous bodies? Give an example of isomorphism in the case of the alums. What general conclusion may be drawn from these facts? How many isomorphous groups have been determined Enumerate the members belonging to each.

6.	
Hypermanganic Acid .	$Mn_2\,O_7$
Hyperchloric Acid . .	$Cl\,O_7$
7.	
Salts of Potash . . .	$K.O$
Salts of Oxide of Ammonium	$Am\,O$
8.	
Oxide of Silver . . .	$Ag\,O$
Oxide of Sodium . .	$Na\,O$
9.	
Baryta	$Ba\,O$
Strontia	$Sr\,O$
Lime (in arragonite) .	$Ca\,O$
Oxide of Lead . . .	$Pb.O$
10.	
Lime (in Iceland spar)	$Ca\,O$
Magnesia	$Mg\,O$
Protoxide of Iron . .	$Fe\,O$
" Manganese	$Mn\,O$
" Zinc . .	$Zn\,O$
" Cobalt . .	$Co\,O$
" Nickel . .	$Ni\,O$
" Copper . .	$Cu\,O$
" Lead (in plumbo calcite) . .	$\dot{Pb}.O$

From the external forms of bodies we may next turn to their internal constitution, calling to mind what has been already observed in Lecture XXXV., that identity of composition by no means implies identity of character. Two substances may be composed of the same elements, united in the same proportions, and yet be totally unlike; and it is obvious that this may be due to two different causes: 1st. Difference of grouping; 2d. Difference in the absolute number of atoms.

Difference of grouping I have already explained in the lecture just quoted; and with respect to difference in the absolute number of atoms, the effect is obvious from an example. Thus, we have as the constitution of

Aldehyde	$C_4H_4O_2$.
Acetic ether	$C_8H_8O_4$.

And these bodies, if analyzed, would, of course, yield precisely the same proportions in 100 parts, the true difference being, that the atom of acetic ether contains twice as many constituent atoms as that of aldehyde, and is, therefore, exactly twice as heavy, though equal weights of the two will yield equal quantities of their constituents.

To these peculiarities the term isomerism is applied, and by isomeric bodies we mean bodies composed of the same elements in the same proportion, but differing in properties. When isomerism arises from difference in grouping, the bodies are said to be metameric; and when it arises from difference in the absolute number of atoms, they are called polymeric.

Attention has recently been drawn to a third cause, which

What two causes may give to bodies of the same composition different characters? Give an example of the effect of difference of the absolute number of atoms. What is meant by isomerism? What are metameric bodies? What are polymeric bodies?

gives rise to the phenomena of isomerism: it is the allotropic condition of elementary bodies. Carbon, for example, exists under a number of different forms; we find it as charcoal, plumbago, and diamond. They differ in specific gravity, in specific heat, and in their conducting power as respects caloric and electricity. In their relations to light, the one perfectly absorbs it, the second reflects it like a metal, the third transmits it like glass. In their relation to oxygen they also differ surprisingly; there are varieties of charcoal that spontaneously take fire in the air, but the diamond can only be burned in pure oxygen gas. The second and third varieties do not belong to the same crystalline form.

It is now known that a great many elementary substances are affected in this manner. I have shown that this is the case with chlorine gas, which changes under the influence of the indigo rays (*Phil. Mag.*, July, 1844). In the same manner, it has been long known that iron exists in two states: 1st. In its ordinary oxydizable state; 2d. In a condition in which it simulates the properties of platinum or gold.

There can be no doubt that these peculiarities are carried by these bodies when they unite to form compounds; thus, for example, if carbon and hydrogen unite, it is possible we may have three different compounds; one containing charcoal carbon, a second plumbago carbon, a third diamond carbon; or, if we designate these respectively as Ca, $C\beta$, $C\gamma$, we may have

$$CaH \ldots C\beta H \ldots C\gamma H;$$

and perhaps, as M. Millon has suggested, carbureted hydrogen gas and otto of roses, which have the same constitution, differ, in the one containing charcoal and the other diamond.

These peculiarities are known under the name of allotropic states, and the phenomenon itself under the designation of allotropism.

What is meant by the allotropic condition of bodies? What allotropic states does carbon present? How may an allotropic change be impressed on chlorine? What are the allotropic states of iron? Are these peculiarities continued in the compounds?

LECTURE XXXVIII.

CHEMICAL AFFINITY.—*Phenomena accompanying Chemical Affinity.—Disturbance of Temperature.—Production of Light.—Evolution of Electricity.—Change of Color.—Change of Form.—Change of Chemical Properties.—Change of Volume and Density.—Tables of Geoffroy.—Measure of Affinity.—Disturbing Causes.*

BY chemical affinity we mean the attraction of atoms of a dissimilar nature for each other, an attraction which is exhibited upon the apparent contact of bodies.

There are certain striking phenomena which very frequently accompany chemical action. They are the evolution of Light, Heat, and Electricity; and, as respects the bodies engaged, they may exhibit changes of color, of form, of volume, of density, or of their chemical properties.

If, in a glass vessel, *a* (*Fig.* 151), a mixture of strong sulphuric acid and water be stirred together by means of a tube, *b*, containing some sulphuric ether, so much heat will be evolved by the acid and water as they unite, that the ether will be made to boil rapidly.

Fig. 151.

If, upon some water contained in a shallow dish (*Fig.* 152), a piece of potassium be thrown, the potassium decomposes the water with the evolution of a beautiful lilac flame.

Fig. 152.

As respects the evolution of electricity during chemical action, the Voltaic battery, and, indeed, all Voltaic combinations, are examples. In the simple circle we have already, in Lecture XXIX., traced the production of electricity to the decomposition of the water.

We have observed that the evolution of the imponderable agents is not the only phenomenon to be remarked during the play of chemical affinity; the ponderable substances themselves undergo changes.

What is meant by chemical affinity? What phenomena accompany chemical action? What changes are exhibited by the ponderable bodies themselves? Give examples of the evolution of heat, light, and electricity.

If, in a glass containing litmus water, a drop of sulphuric acid is poured, the blue color of the litmus is at once changed to a red, and if into the reddened fluid so produced a little ammonia is poured, the blue color is restored. This simple experiment is of considerable interest, for the reddening of litmus is commonly received as one of the attributes of acid bodies, and the restoration of the blue color of those belonging to the alkaline type.

On adding to a solution of sulphate of copper a small quantity of ammonia, a pale green precipitate is thrown down; a greater quantity of ammonia redissolves this precipitate, and gives rise to a splendid purple solution.

A similar solution of sulphate of copper gives rise, under the action of a solution of ferrocyanide of potassium, to a deep chocolate-colored precipitate.

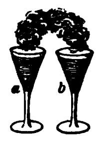
A solution of the nitrate of lead, which is colorless, acted on by a solution of iodide of potassium, also colorless, gives rise to the production of a beautiful yellow precipitate, the iodide of lead.

And, lastly, if sulphuric acid be placed in a solution of a soluble salt of lead, or of baryta, a white precipitate at once goes down.

These are all instances of changes of color, and such changes are of the utmost importance in practical chemistry, inasmuch as the art of testing depends, for the most part, upon a knowledge of them.

Changes of form in the same manner are exhibited; thus, when gunpowder explodes, a large proportion of the ingredients, from being in the solid, escapes in the gaseous state. If, upon fragments of chalk, carbonate of lime, we pour hydrochloric acid, a violent effervescence takes place, due to the escape of carbonic acid, which, from being in the solid, assumes the gaseous form.

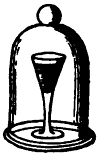
Fig. 153.



The converse of this is sometimes seen, vapors passing into the solid state. In the glass, *a* (*Fig.* 153), place some strong hydrochloric acid, and in *b* some strong ammonia; both these bodies yield vapors at ordinary temperatures in abundance, and those vapors meeting in the air over the glasses, give rise to a dense fume or smoke, which, if examined, proves to be solid sal ammoniac.

Give examples of changes of color. On what do the processes of testing for the most part depend? Give an example of the production of a gas from a solid, and a solid from gases.

Fig. 154.



Very often change of form is accompanied by change of color; thus, if under a large bell jar (*Fig.* 154) there is placed a wine-glass containing a few copper or iron nails and nitric acid, a gas of a deep orange color makes its appearance, filling the whole bell.

Perhaps no better instance of an entire change of properties could be cited than that of the combustion of phosphorus in atmospheric air. This substance, phosphorus, is a body of a waxy appearance, possessing so great a degree of combustibility that it requires to be kept under the surface of water to prevent the action of the air. If a piece of it be set on fire beneath a clear and dry bell jar, as shown in *Fig.* 155, it unites with great energy with the oxygen of the included air, producing white flakes, which, as the combustion is ceasing, descend in the jar, giving a miniature representation of a fall of snow. On collecting some of this phosphoric snow, its properties will be found to be in striking contrast with the phosphorus which produced it; for instance, far from being unacted on by water, it has such an intense affinity for that substance, that it hisses like a red-hot iron when brought in contact with it. It reddens litmus solution, and possesses the qualities of a powerful acid. Nor is the change confined to the phosphorus; if we examine the air in which it was burned, we find it has lost its quality of supporting combustion.

Fig. 155.

Changes of volume, and, consequently, changes of density, constantly attend chemical action; a pint of water and a pint of sulphuric acid, mixed together, form less than two pints; and the same may be observed of alcohol and water.

When to two substances already in union, a third, having a stronger affinity for one of the other two, is presented, decomposition ensues. Thus, if to the carbonate of soda nitric acid be presented, the soda and nitric acid combine, and the carbonic acid is driven off in the form of a gas. And, again, if upon the nitrate of soda so produced sulphuric acid is poured, the nitric acid is driven off, and sulphate of

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What are the changes which phosphorus undergoes when burned in the air? Give an example of change of volume and of density. Under what circumstances does decomposition take place?

soda results. It was at one time thought that, by examining a number of such cases, we might discover the order of affinity of bodies for one another, and arrange them in tables; these are sometimes called the Tables of Geoffroy. Thus, the table

Soda.

Sulphuric acid,
Nitric "
Muriatic "
Acetic "
Carbonic "

presents us with the order in which a number of acids stand in relation to soda, the most powerful being the first on the list, and the salt which results from the union of any one of those acids with the soda can be decomposed by the use of any other acid standing higher on the list.

But it is now known that these tables are far from representing the order of affinities; a weaker affinity often overcomes a stronger, by reason of the intervention of disturbing extraneous causes; and tables so constructed lead, therefore, to contradictory conclusions. Some very simple considerations may illustrate this. Potassium can take oxygen from carbon at low temperatures, or, in other words, decompose carbonic acid gas, but it by no means follows that the affinity of potassium for oxygen is greater than that of carbon, and accordingly we find that at higher temperatures carbon can take oxygen from potassium. Indeed, under the influence of heat, light, and electricity, we find all kinds of chemical changes going on, and in the same manner the condition of form exerts a remarkable influence in these respects, so that cohesion and elasticity may be placed among the predisposing causes producing chemical results. If a number of bodies exist in a solution together, they will at once arrange themselves in such a way under the influence of cohesion as to produce insoluble precipitates, if that be possible; or, under the influence of elasticity, to determine the evolution of a gas; if the carbonate of soda is decomposed by acetic acid, it by no means follows that the latter has the stronger affinity for soda, the decomposi-

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What are the tables of Geoffroy? How may it be shown that these are not the tables of affinity? What may be enumerated among these disturbing causes? What is the influence of cohesion? What is the influence of elasticity? Give examples of the action of these disturbing agents.

tion being probably determined by the fact that the carbonic acid can take on the elastic form and escape away as a gas. The sulphate of soda may be decomposed by baryta, the cause of the decomposition being probably due to cohesion, for the sulphate of baryta which results is a very insoluble body. We have, therefore, no true measure of affinity, for the relation of bodies in this respect changes with external conditions, and the tables of Geoffroy are only tables of the order of decompositions, but not of the order of affinity.

What do the tables of Geoffroy, in reality, express?

PART III.

INORGANIC CHEMISTRY.

LECTURE XXXIX.

PNEUMATIC CHEMISTRY.—*Ancient Opinions on the Constitution of the Gases.—Doctrine of the Unity of Air.*
OXYGEN GAS.—*Modes of Preparation.—Properties.—Origin of its Name.—Relations to Atmospheric Air and Combustion.—Burning of Metals.*

IN the catalogue of the elementary bodies of the ancients four substances were included, earth, air, fire, and water. The progress of knowledge has shown that three out of the four are compound bodies.

For a length of time it was supposed that the variout exhalations and vapors were nothing more than vitiated forms of atmospheric air; and though from time to time first one and then another of the gaseous bodies was discovered, chemists were slow to admit that they were any thing more than modifications of one common principle. Thus, Roger Bacon, in the thirteenth century, discovered one of the carburets of hydrogen, and Van Helmont, in the sixteenth, carbonic acid. The invisibility of these bodies, their remarkable chemical relations in extinguishing flame and producing death, the great mechanical force to which they often gave rise when generated in pent-up vessels, their occurrence in mines, the bottom of wells, in church-yards and lonely places, suggested to a superstitious mind a supernatural origin, and Van Helmont gave them the name of gas, corrupted from gahst (or geist), which signifies a ghost or spirit.

But it is to the researches on the properties of fixed air, which Black made about 1750, that pneumatic chemistry owes its origin. These were soon followed by the discoveries of Priestley, Scheele, and others. That of oxygen gas,

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What opinions were formerly held respecting the different gases? What was the original signification of the term gas? By whom was the doctrine of the plurality of airs established?

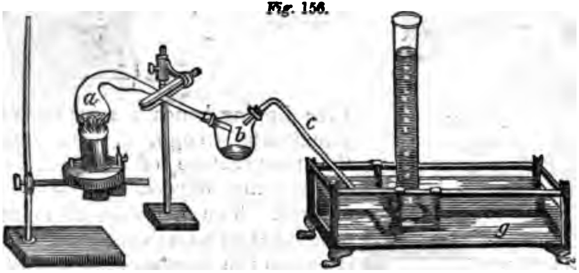
by the former of these philosophers, in 1784, forever destroyed the ancient notion of vitiated airs; for this gas can support combustion and respiration far better than the atmosphere. It may be said with justice that modern chemistry dates its origin from the discovery of oxygen gas.

OXYGEN. $O = 8{\cdot}013$.

Oxygen gas is probably the most abundant of the elements. It constitutes about one third of the weight of the solid mass of the earth, eight ninths of that of the waters of the sea, and one fifth the volume of the air.

A simple mode of preparing oxygen is to place in a retort, *a*, *Fig.* 156, some red oxide of mercury, connecting with the retort a receiver, *b*, from which there passes a bent tube, *c*, which dips beneath the water of a pneumatic trough, *g*. On raising the temperature of the oxide by the flame of a spirit lamp, it is resolved into metallic mercury and oxygen gas; the former distills into the receiver *b*, and the latter collects in the inverted jar of the trough.

Fig. 156.



Another process is to place the peroxide of manganese ($Mn. O_2$) in an iron bottle, from which a tube, *b*, *Fig.* 157, projects; this tube may be connected with another, *f*, by means of a cork and an India-rubber tube, *e*. The bottle is to be arranged in a small furnace, and made red hot; the manganese loses one fourth of its oxygen, which may be collected in a gas-holder, as shown in the figure.

The most convenient mode of preparing it is to place in a flask, *a*, *Fig.* 158, a mixture of chlorate of potash and peroxide of manganese; to the mouth of the flask a tube, *b*, is adapted by means of a tight cork, the lower end of the

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In what bodies does oxygen occur? Describe its preparation from red oxide of mercury, from peroxide of manganese, and from chlorate of potash.

Fig. 157.

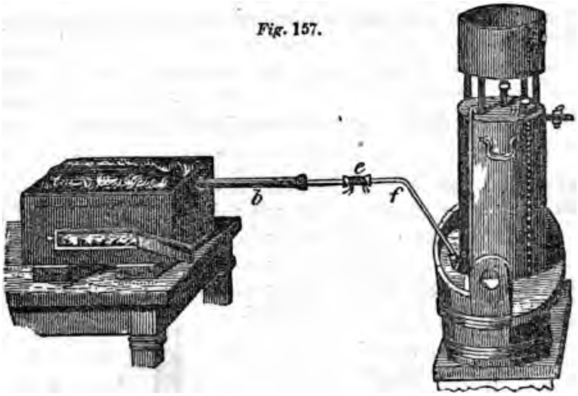
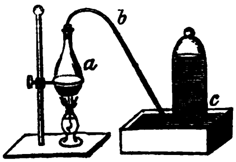


Fig. 158.



tube dipping beneath a jar upon the pneumatic trough, *c*. On raising the temperature of the flask by a spirit lamp, oxygen gas is freely evolved. The peroxide of manganese takes no part in the change, but it causes the decomposition to go on at a low temperature, and the gas is more rapidly set free. The change, being confined to the chlorate of potash, is therefore expressed as follows:

$$K\,O + Cl\,O_5 \ldots = \ldots K\,Cl + O_6\,;$$

that is, the chlorate of potash, at the temperature in question, has its atoms disarranged, resolving itself into one atom of chloride of potassium and six atoms of oxygen gas.

It may also be prepared by exposing a mixture of bichromate of potash and sulphuric acid, or peroxide of manganese and sulphuric acid, to heat.

Oxygen gas is a colorless body, having no odor nor taste. It is a non-conductor of electricity, and a bad refractor of light. It is a powerfully electro-negative element. In specific gravity it is heavier than atmospheric air; for the being 1·000, oxygen is 1·1026, or, according to some chemists, 1·1111. One hundred cubic inches weigh about 34 grains. Its atomic weight is 8·013, hydrogen being taken

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What are its leading physical properties? What is its specific gravity?

as 1·000. It has never been condensed into the liquid state.

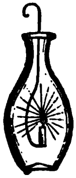
To a certain extent it is soluble in water, one hundred volumes of that liquid dissolving about four of the gas, a fact of considerable importance in physiology, as it is upon the oxygen so found in water that aquatic animals depend for their respiratory process.

On litmus water, or any blue vegetable solution, oxygen exerts no action, as it is easily shown by agitating it with such a solution in Hope's eudiometer (*Fig.* 159); but, though it is not acid itself, when it unites with a great variety of bodies it gives rise to powerful acids, and from this circumstance its name was derived. Oxygen, οξυς, acid, and γεννειν, to generate.

Fig. 159.

The most important qualities of atmospheric air are due to the presence of oxygen gas. It is for this reason that the air supports combustion and respiration. The powers of oxygen, in this respect, may be illustrated by many striking experiments; thus, if into a jar filled with it, a stick of wood, with a spark of fire on its extremity, be immersed, it bursts out at once into a flame, burning brilliantly.

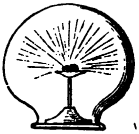
Fig. 160.



On immersing a lighted taper in a jar of oxygen (*Fig.* 160), the light becomes of a dazzling whiteness, the taper wasting rapidly away; but it is to be observed that after a time the combustion declines, and finally the light is extinguished.

If a piece of charcoal of bark in an ignited state be placed in a bottle of oxygen, the combustion goes on with great activity, a multitude of sparks being thrown off. When the charcoal is extinguished, if a little lime-water be poured into the bottle and agitated in it, the lime-water at once becomes of a milky whiteness; for the carbon, during the combustion, uniting with the oxygen, produces carbonic acid gas, and this forms with lime a white insoluble precipitate, the carbonate of lime.

Fig. 161.



Can it be liquefied? Is it soluble in water? From what circumstance is its name derived? What are its relations in the ordinary processes of combustion? **Describe its effect on a lighted taper and on ignited charcoal.**

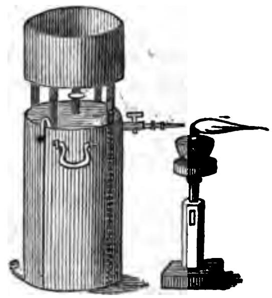
A piece of India-rubber set on fire, and immersed in oxygen gas, burns with the emission of a dazzling light. And if, upon a small stand, some burning sulphur is placed, and a jar of oxygen inverted over it, as shown in *Fig.* 162, the light which is emitted is of a splendid blue color, and the smoke ascending up the middle of the jar, and falling in curious rings down its sides, affords an illustration of the manner in which currents are excited in gases.

Fig. 162.

But it is not alone such substances as wood, charcoal, or sulphur which will burn in oxygen gas; many bodies commonly regarded as incombustible give rise to the same result. If a piece of steel wire be rolled round into a spiral, and the extremity of it be dipped in melted sulphur, or wrapped round with cotton, so as to afford the means of introducing it in an ignited condition into oxygen gas, the combustion is at once communicated to the steel, which burns in a very brilliant manner, emitting scintillations.

Fig. 163.

Fig. 164.



A stream of oxygen from a gas-holder, being thrown upon an iron nail made red hot in the flame of a spirit lamp, or placed in an ignited cavity in a piece of charcoal, causes the iron to burn with rapidity, emitting a shower of sparks.

When a stream of electric sparks is passed through dry and pure oxygen, a part of the gas undergoes a remarkable change, its chemical affinities being for the most part greatly exalted, and a peculiar phosphoric odor communicated to it. A similar change is often remarked in oxygen which has been set free from the decomposition of water by the Voltaic battery, and also in damp atmospheric air in which sticks of phosphorus have been slowly oxydizing. To this substance the name of OZONE has been given; but it is now generally regarded as an allotropic

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What is its effect on ignited sulphur? What is its effect on an ignited metal, as iron or steel? How is ozone formed?

modification of oxygen, and that this substance, like carbon, phosphorus, or chlorine, can exist in two different conditions, an active and a passive state.

Active oxygen or *ozone* readily decomposes iodide of potassium, sulphate of manganese, and yellow ferrocyanide of potassium. It is not soluble in water, is destroyed by a heat of 140°, and by contact with several hydro-carbons.

LECTURE XL.

OXYGEN CONTINUED.—*Drummond's Light.—Combustion of Phosphorus.—Double Change arising in Combustion.—The Lavoisierian Doctrine.—Basic, Indifferent, and Acid Oxides.—Physiological Relations of Oxygen.—Supporters of Combustion.—Nature of Flame.—Constancy of Heat evolved.—Vegetable Origin of Oxygen in the Air.*

IF a piece of lime the size of a peppercorn be placed in the flame of a spirit lamp, through which oxygen gas is directed by a blowpipe, the lime phosphoresces powerfully, emitting a light so bright that the eye can scarcely bear it. This is the original form of what is called Drummond's light. The light, however, is still brighter when the oxy-hydrogen blowpipe is employed.

The combustion of phosphorus in oxygen gas constitutes one of the most brilliant experiments. A piece of lighted phosphorus immersed in an atmosphere of this gas, burns with the evolution of a prodigious amount of light and heat, *Fig.* 165. Notwithstanding the production of dense flakes of phosphoric acid intervening between the eye and the burning mass, the light is very brilliant.

Fig. 165.

When any combustible substance is burned in oxygen gas, two striking phenomena are exhibited: a change in the combustible, and a change in the oxygen. A fragment of

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What are its properties? What is the original form of the Drummond light? What are the phenomena of the combustion of phosphorus in oxygen? In these combustions, what changes take place in the oxygen and in the burning body?

ignited charcoal rapidly wastes away, and the surrounding gas loses its power of supporting combustion. Until the time of Lavoisier, it was generally supposed that burning was due to the escape of a certain principle, called phlogiston, from bodies, but he showed that in all these cases there is no loss of weight, and that, in reality, the combustion is due to the oxygen uniting with the burning body; and if care be taken to collect all the products of the action, their united weight will be exactly that of the oxygen and combustible conjointly. Lavoisier was disposed to believe, that in all cases of true burning the presence of oxygen is indispensable, an idea now known to be erroneous; for light and heat are evolved in all cases where chemical action is going on with great intensity, no matter what may be the substances which happen to be present.

In the Lavoisierian system of chemistry, oxygen was regarded as being the essential supporter of combustion; and as, in many instances, it gives rise to the production of acids, it was also regarded as the essential principle of acidity; and from this circumstance its name was derived, as has been already said. But so far from every acid containing oxygen gas, it is now well known that there are many from which this principle is wholly absent. If any substance in particular deserves the name of "the acid former," it is hydrogen, for it is doubtful whether any powerful acid exists which does not contain hydrogen. Basic substances, on the contrary, are characterized by containing oxygen.

To the compounds which arise from the union of oxygen with other bodies, the generic designation of oxides is given, and of them we have three classes. 1st. Basic oxides. 2d. Indifferent oxides. 3d. Acids. If M represents an electro-positive body, the basic oxides are constituted as follows:

MO . . .	Protoxide, usually the most powerful base.
M_2O_3 . . .	Sesquioxide, a weaker base.
MO_2 . . .	Deutoxide, a still weaker base.
M_2O . . .	Suboxide, " "

The oxides of manganese furnish a good example of the three classes:

What was Lavoisier's theory of combustion? What is the relation of oxygen to acid and basic bodies? What is the generic designation for its compounds? What are the three classes of compounds which it yields

Protoxide of manganese	MnO	Basic oxides.
Sesquioxide "	Mn_2O_3	
Deutoxide "	MnO_2	Indifferent oxide.
Manganic acid	MnO_3	Acids.
Hypermanganic acid	Mn_2O_7	

From which it may be inferred that, in a family of oxides of an electro-positive body, the most powerful base is that containing one atom of oxygen, and that, as the quantity of this element increases, indifferent bodies may be formed; that is to say, those in which neither the basic nor acid qualities are well marked, and on a still farther increase acids are produced. In this respect, therefore, the original idea of Lavoisier respecting the character of oxygen is to some extent substantiated.

In its physiological relations oxygen is a most interesting body. It is for the purpose of introducing this element to the interior of the system that the respiratory mechanism of animals is devoted—a mechanism which differs according to their mode of life, the gills of a fish and the lungs of a man having the same ulterior object. If two jars are taken, one full of atmospheric air and one of oxygen gas, and small animals placed beneath each, it will be found that in the latter those animals survive much longer than in the former. The gas introduced into the system arterializes the blood, and, eventually uniting with carbon and hydrogen, keeps up the temperature to a standard point, which, in the human mechanism, is about 98° F. Oxygen gas, therefore, is emphatically the supporter of respiration.

The terms, supporter of combustion and combustible body, formerly much used by chemical writers, are expressive of an erroneous idea. No substance is in itself a supporter of combustion, nor is any one intrinsically a combustible body. If a jet of hydrogen burns in an atmosphere of oxygen, so also will a jet of oxygen burn in an atmosphere of hydrogen gas. In fact, both bodies are equally engaged in producing the result, combustion only taking place upon their mutual surface of contact. The division in question has arisen from the circumstance that the most familiar instances of combustion we witness take place in the atmos-

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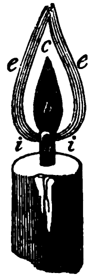
In the basic, the indifferent, and the acid group, what is the general relation of the oxygen? For what purpose is oxygen introduced into the system? Why is it to be regarded as the supporter of respiration? Is the division of bodies into combustibles and supporters of combustion a correct one?

phere, which owes all its active qualities to the presence of oxygen.

Combustion takes place only at those points where the uniting substances are in contact. The flame of a candle is not incandescent throughout, but is a mere superficies or luminous shell, with a dark interior. In such a flame several distinct parts may be traced. Around the wick, *a*, *Fig.* 166, at the points *i i*, the light is of a blue color; for here the air being in excess, the combustion is perfect. From this toward *c* the combustible matter predominates, and the light is most intense. A faint exterior cone, *e e*, surrounds the more luminous portion, but the interior at *b* is totally dark, as may be proved by placing a piece of mica or glass upon the flame. It is probable that the light arises chiefly from the ignition of solid matter, for incandescent gases are only faintly luminous. The hydrogen of the flame is first burned, and for a moment carbon is set free in the solid form at a very high temperature, its oxydation instantly ensuing.

Fig. 166.



A given weight of a combustible body, when burned, will always furnish a constant amount of heat. If an ounce of carbon be burned in a few moments in pure oxygen gas, the amount of heat disengaged appears to be very great; though, in reality, it is the same that would finally be yielded by a slower combustion in atmospheric air. So, too, metallic iron becomes quite hot when burned in oxygen, because the combination goes forward with great rapidity; but precisely the same amount would be yielded in the slow oxydation of rusting, though in the latter instance it might take years for the completion of the process. This is a fact of great physiological importance.

We have just said that atmospheric air owes all its activity to the presence of oxygen, and as there are incessantly combustive processes going on, the tendency of which is to remove oxygen from the air and generally replace it with carbonic acid—a result, also, which ensues from respiration, in every part of the earth where animals are found—it would appear a necessary consequence that the consti-

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What is the nature of flame? Why do the different regions of a lamp flame differ in luminous power? Is there any difference in the amount of heat evolved in rapid and in slow combustions?

tution of the air should incessantly change, the amount of oxygen declining and that of carbonic acid increasing. But in this respect the vegetable world exerts an opposite tendency to the animal; for, under the influence of the light of the sun, plants decompose carbonic acid gas, setting free its oxygen, and appropriating the carbon to their own uses. This beautiful fact was originally discovered by Priestley, who found, that if some green leaves were placed in a bottle, as in *Fig.* 167, containing carbonic acid gas, or, what is more convenient, water holding that substance in solution, so long as the sun does not shine on them, no action is perceived; but if the bottle be set in the sun, bubbles of gas are rapidly disengaged from the leaves, and, rising up through the water, collect in the upper part of the bottle, and, if examined, prove to be very rich in oxygen.

Fig. 167.

A question has arisen as to what principle the remarkable decomposition is due. I have proved, by causing it to take place in the prismatic spectrum, that it is due to the yellow ray of light.—(*Phil. Mag., Sept.*, 1843.)

LECTURE XLI.

HYDROGEN.—*Preparation and Properties of Hydrogen.—Relations to Respiration.—Combustibility.—Its Lightness.—Explosive Combustion.—Production of Water.—Oxhydrogen Blow-pipe.*

HYDROGEN. $H = 1$.

IF a piece of potassium be wrapped in paper and rapidly immersed beneath an inverted jar at the water-trough, violent reaction soon sets in, a gas collects in the upper part of the jar, and the potassium, oxydizing, dissolves in the water. The gas so produced is hydrogen, and the decomposition is very simple, as shown in the following symbols:

$$HO + K \ldots = \ldots KO + H;$$

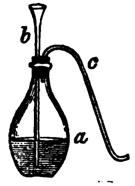
that is, water acted upon by metallic potassium yields oxide of potassium and hydrogen gas.

What are the causes which tend to diminish the amount of oxygen in the air? By what agency is this tendency compensated? What is the principle of the decomposition of water by potassium?

In practice more economical processes are resorted to. Like potassium, metallic zinc can decompose water at ordinary temperatures, but there is this difference between them, that while the oxide of potassium is very soluble in water, the oxide of zinc is nearly insoluble. A plate of polished zinc immersed in water does not, therefore, give rise to a stream of gas, for the moment the incipient action has set in it ceases, the zinc becoming covered with an impervious pellicle of oxide, which cuts off farther contact with the water.

If, however, we add any acid substance which can form with the oxide a salt soluble in water, the action will go on continuously, because the zinc can now expose a clear metallic contact. Such a substance is sulphuric acid. To make hydrogen, therefore, we take a bottle, *a*, *Fig.* 168, and having placed in it some strips of zinc, add sufficient water to cover them entirely, and then adjust to the mouth of the bottle a cork, through which two tubes, *b* and *c*, pass. Through *b* sulphuric acid is poured in such a quantity as to excite a brisk but not too violent effervescence, and the gas, as it generates, passes out through *c*. It is absolutely necessary to allow a quantity of the gas to escape before attempting to collect it, because the first portions form, with the air in the upper part of the bottle, an explosive mixture; but as soon as it is judged that the air is all expelled, we may proceed to collect the gas; and whenever the production slackens, if more acid be added through the funnel tube, *b*, the supply may be kept up.

Fig. 168.



Hydrogen gas is a transparent and colorless body, which exerts a powerful refracting action on light. When pure, it has neither taste nor smell, but, as thus obtained, it has a peculiar odor. It is the lightest body in nature, its specific gravity being 0·0694. One hundred cubic inches of it weigh 2·1 grains. The weight of its atom is taken as the standard of comparison of other atomic weights in this book; it is therefore = 1. It exerts no action on vegetable colors, and is very sparingly soluble in water, one hundred cubic inches of that liquid dissolving about one and a half of hydrogen gas. Hydrogen has never been liquefied.

What is the reason that zinc can not decompose water alone? How may hydrogen gas be made by the aid of zinc? What are the properties of this gas?

As respects the animal economy, hydrogen gas does not exert any directly deleterious effect; and although it can not, of course, carry on the functions of respiration, which are acts of oxydation, yet it can, for a short space, be introduced into the lungs with impunity. If a person whose lungs are inflated with it attempts to speak, his voice resembles the feeble and shrill voice of a child. This arises from the small density of hydrogen; a bell rung in this gas emits almost as feeble a sound as if rung in a vacuum.

Fig. 169.

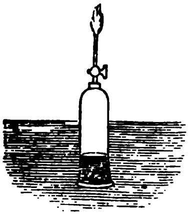
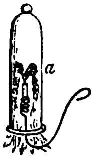


Fig. 170.

One of the most striking peculiarities of hydrogen is its great inflammability in contact with oxygen. If a jar, *Fig.* 169, with a stopcock at its upper extremity, be filled with hydrogen, and then, being depressed in the water of the trough, the cock opened and a light brought near the hydrogen as it escapes, it takes fire at once, burning with a pale yellow flame. Or if to the mouth of a bottle containing the materials for generating hydrogen, *a*, *Fig.* 170, a cork, through which a glass tube, *b*, is passed, be adjusted, and after allowing the air in the bottle to be displaced, a light be applied to the issuing gas, it takes fire and burns in the same manner; an experiment commonly described as the philosophical candle.

Fig. 171.



The following experiment proves three facts at the same time: 1. The great lightness of hydrogen; 2. Its inflammability; 3. That it is not a supporter of combustion. A jar, *a*, *Fig.* 171, is to be filled with hydrogen at the water-trough, and then, being lifted in the air with its mouth downward, a taper, placed on a bent wire, is carried into its interior. As the taper passes the mouth of the jar there is a feeble explosion, and the hydrogen, taking fire, burns with a pale flame; but as soon as it is immersed in the atmosphere of the gas the taper is extinguished. It may, however, be relighted as it is brought out of the jar at the burning hydrogen, and this may be repeated several times in succession. The combustibility of the gas and its

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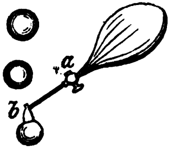
What are its relations to respiration? How may its combustibility be demonstrated? How may its inflammability, its non-supporting power, and its lightness be simultaneously illustrated?

quality of not supporting combustion are obvious enough, and its lightness is proved by the fact that it does not flow out of the open mouth of the jar, which it would do at once if it were heavier than atmospheric air.

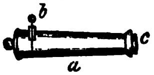
The application of hydrogen to aerostatic purposes is founded upon its small specific gravity. This property is very distinctly illustrated by filling an India-rubber gas-bag with hydrogen, and having attached to the stop-cock, *a*, *Fig*. 172, which closes it, a common earthen-ware tobacco-pipe, *b*, by dipping the pipe in a solution of soap, bubbles may be blown. These rise through the air with rapidity; and if a lighted taper is brought near them as they are ascending, the hydrogen takes fire and burns with a yellowish flame.

Fig. 172.



If, in a strong brass vessel, *a*, *Fig*. 173, we place a mixture of hydrogen and atmospheric air in equal volumes, and, having inserted the cork, *c*, tightly, pass, by the aid of the ball and wire, *b*, an electric spark through the gas, a violent explosion takes place, the hydrogen burning instantaneously with the atmospheric oxygen, and giving rise to the production of water.

Fig. 173.



Musical sounds originate in vibratory movements communicated to the air. If the flame of a philosophical candle is covered by a wide glass tube, as, for example, the neck of a broken retort, an intensely powerful sound is emitted. This arises from the circumstance that the hydrogen burns in the tube, giving rise to a series of small explosions, which follow each other with rapidity, and these explosions throw the air in the tube into a vibratory state. According as the tube is raised or lowered, these explosions occur with different degrees of rapidity, sometimes producing a clattering sound, and then a pure musical note.

Fig. 174.

Whatever may be the circumstances under which hydrogen burns, whether quietly, as in the philosophical candle, or with trivial explosions, as in this tube, or with a violent detonation, as in the preceding experiment, the uniform pro-

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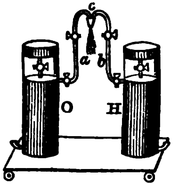
To what purpose is hydrogen applied in consequence of its lightness? How may this be illustrated on a small scale? When mixed with oxygen or air, and an electric spark passed through it, what is the result? Under what circumstances will the flame of hydrogen emit a musical sound?

duct of the combustion is water. During the combination of these elementary bodies with each other a very great amount of heat is given out, for hydrogen combines with eight times its own weight of oxygen, a greater proportion than is met with in the case of any substance whatever. Advantage is taken of this in the construction of the oxyhydrogen blow-pipe, an instrument invented by Dr. Hare, which furnishes us with the most efficient means of obtaining a high temperature. There are several different forms of this blow-pipe; in some the gases are mixed in the proper proportions in a strong receiver, and set on fire after passing through a Hemming's safety tube. But it is better to keep them in separate reservoirs, and conduct them to a common jet, where they may simultaneously mix and be burned, as is shown in *Fig.* 175, where O is the oxygen reservoir, H the hydrogen, *a b* the flexible lead pipes, leading to a common jet, *c*, at which the gases are set on fire. By this instrument substances perfectly infusible in a common furnace melt at once. The intensity of the heat of this blow-pipe depends, to a great extent, on the fact that, unlike ordinary flames, the oxyhydrogen flame is, as it were, solid; that is, incandescent throughout all its parts.

Fig. 175.



In its general relations, hydrogen possesses so many of the properties of the metallic class, that there is every reason to believe it is, in reality, a metal. The facts of its aerial form and transparency can scarcely be regarded as of any weight against this conclusion, for the vapor of mercury possesses a similar aspect.

What is the uniform production of its combustion? Why is so much heat evolved in the burning of a mixture of oxygen and hydrogen? Describe Hare's compound blow-pipe. What is the peculiarity of the flame? To what class of bodies does hydrogen probably belong?

LECTURE XLII.

WATER.—*Hydrogen Acids.—Water.—Its Properties.—Compressibility.—Constitution of Water.—Syntheses of Water.—By Spongy Platinum.—Determination of its Composition by Weight.—Analysis of Water.—Chemical Relations of Water.—Water of Crystallization and Saline Water.—Acts as a basic, indifferent, and acid Body.—Purification.—Deutoxide of Hydrogen.*

WATER. $HO = 9{\cdot}013$.

HYDROGEN unites with all the electro-negative substances, and, with many of the more prominent ones, forms strong acids. The hydrogen acids of chlorine, bromine, iodine, and fluorine are all constituted upon the same type, in which, if the electro-negative radical be represented by R, we have

$$HR.$$

But with oxygen, instead of an acid, a neutral body results. This body is common water.

Water, as will be presently proved, results from the union of oxygen and hydrogen, one atom of each of these elements combining to form one atom of water. It is, therefore, a binary compound. Its symbol is

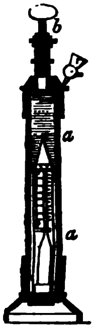
$$HO.$$

By volume, it consists of two of hydrogen united with one of oxygen; by weight, one part of hydrogen united with eight of oxygen. These statements correspond with the first, because the hydrogen atom is twice the volume of that of oxygen; and the weight of an atom of oxygen is eight times that of hydrogen.

Water is a colorless and tasteless body. It freezes at 32° F., and boils at 212° F. Its specific gravity is 1·000, being the standard of comparison of all other liquid and solid bodies. The specific gravity of its vapor, steam, compared with atmospheric air, is 0·6201. It is a compressible and elastic substance. One cubic inch of it at 62° weighs 252·45 grains.

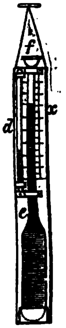
When hydrogen unites with electro-negative substances, what class of bodies arise? What is the constitution of water? What are the properties of water?

Fig. 176.



The compressibility of water is at once demonstrated and measured by an instrument invented by Œrsted, and represented in *Fig*. 176. It consists essentially of a strong glass cylinder, *a a*, filled with water, upon which a powerful pressure can be exerted by means of a piston driven by a screw, *b*. In this cylinder of water a gage, represented on a larger scale by *Fig*. 177, is placed. The gage consists of a reservoir, *e*, prolonged into a fine tube, *f*; there is also a scale annexed. The reservoir and part of the tube are filled with water, and a small column of quicksilver, *x*, indicates the point on the tube to which the water reaches. The pressure exerted is measured by an air-gage, *d*.

Fig. 177.



If now this instrument be placed in the strong glass cylinder, as seen in *Fig*. 176, and pressure exerted by turning the screw, the air in the gage, *d*, contracts, and indicates the amount of that pressure; at the same time, the small column of mercury, *x*, descends in the tube, showing that the water contracts, and measuring its amount. On turning the screw the other way, so as to relieve the apparatus of pressure, the air-gage comes back to its original point, and the mercury in the fine tube ascends again. It is obvious, therefore, that by this instrument we measure the compressibility of the water contained in the reservoir, *e*, due allowance being made for the minute amount of contraction which the glass of which *e* is made, and which is pressed equally on its inside and outside, undergoes; and also for variations of temperature. Œrsted's instrument shows that water is compressed $\frac{1}{22000}$ part of its volume for each atmosphere of pressure.

Fig. 178.

The constitution of water was first clearly proved by Mr. Cavendish. It can be illustrated in a variety of ways. Thus, if over a jet of burning hydrogen a cold glass bell be suspended, as in *Fig*. 178, it becomes soon covered with a misty dew, and, if the experiment be prolonged, drops of liquid finally trickle down the sides, and may be caught in a vessel placed to receive

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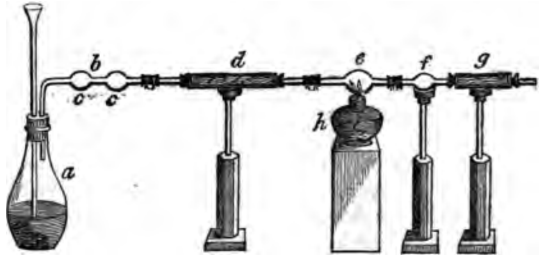
Describe Œrsted's instrument for proving its compressibility. What is the amount of its compressibility? How may its composition be synthetically illustrated?

them. When examined, this liquid is found to be water. It has arisen from the union of the hydrogen with atmospheric oxygen.

If in a vessel over the mercurial trough twenty measures of pure hydrogen are added to ten measures of pure oxygen, and a small pellet of spongy platinum passed up through the quicksilver, union between the two gases rapidly takes place, so that it is usual, in order to moderate its action, to mix the spongy platina previously with a little pipe clay. As the gases unite, the mercury rises, until at last they have totally disappeared. This beautiful experiment shows that the constitution of water by volume is 2 of hydrogen to 1 oxygen, as has already been said.

The composition of water by weight was determined by Berzelius as follows: Let a flask, *a*, *Fig.* 179, containing zinc and dilute sulphuric acid, be connected by a bent tube, *b*, with another tube, *d*, containing chloride of calcium; the hydrogen which is consequently evolved from the flask deposits any small quantity of water it may be contaminated with in the bulbs *c c*, and then passing through the chloride of calcium tube, *d*, is made perfectly dry. The tube *d* is connected with a tube of hard glass, on which a bulb, *e*, is blown. This bulb is filled with a known weight of oxide of copper, which can be raised to a red heat by means of a spirit lamp, *h;* and as the dry hydrogen passes over the ignited oxide, it reduces it, forming with its oxygen water, and leaving pure metallic copper. The water thus produced is partially collected in the bulb *f*, and the rest of it is detained by a second chloride of calcium tube, *g*.

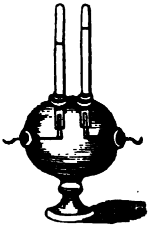
Fig. 179.



How may the constitution of water be proved synthetically by spongy platinum? Describe the method of Berzelius for determining the composition of water by weight.

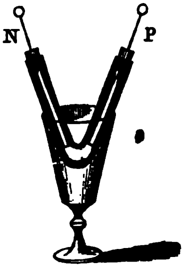
If, therefore, we weigh the tube *e* before and after the experiment, in the latter instance its weight will be less than the former, the difference being due to the amount of oxygen which has been removed. If, also, we weigh the tubes *f* and *g* before and after the experiment, in the latter case they weigh more than in the former, the difference being the weight of water produced. Thus it will be found that for every eight grains that the oxide of copper has lost, nine grains of water have been produced, showing that the constitution of water is by weight 8 of oxygen to 1 of hydrogen.

Fig. 180.



The composition of water may also be proved analytically as well as synthetically. It has been already stated that this can be done by the Voltaic battery in a very satisfactory manner. An apparatus suited for this purpose is shown in *Fig.* 180. The polar wires of the battery enter the sides of a globular glass vessel full of water, and over their terminations tubes are inverted in which to receive the gases. The hydrogen is double the volume of the oxygen.

Fig. 181.



Another form of the same apparatus is seen in *Fig.* 181. In a bent tube full of water, the platina wires, N P, are introduced by means of corks. On the current passing, oxygen is collected in one of the branches of the tube and hydrogen in the other.

Lavoisier determined the composition of water by passing its vapor over pieces of iron made red hot in a tube. Thus, if from the retort, *a*, *Fig.* 182, containing boiling water, steam is passed through a red-hot iron tube, *c c*, filled with turnings of iron, or iron wire, decomposition takes place, black oxide of iron forming, and hydrogen gas escaping by the tube, *f*, into the gas-holder, *m n*.

The chemical relations of water are of the utmost importance. It exerts a more general solvent action than any other liquid known, holding in solution gaseous and solid substances, acids, alkalies and salts. As respects gaseous

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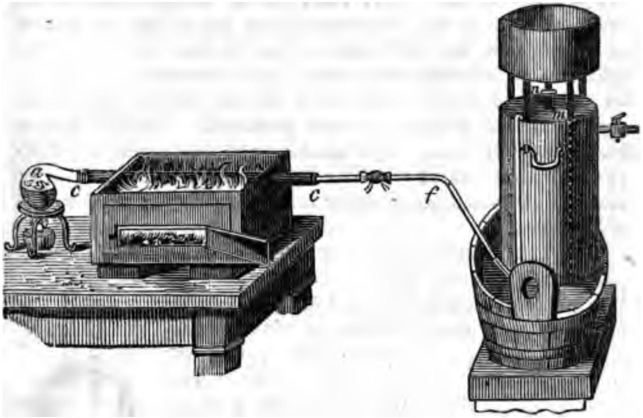
How may the analysis of water be effected? Describe the principle of Lavoisier's analysis of water.

Fig. 182.



bodies, the quantity which water will take up is to a considerable extent dependent on pressure, and in the case of salts, an increase of temperature very frequently increases its solvent power. Salt-crystals sometimes contain a very considerable quantity of it, as is shown in the case of common alum, of which, if a mass be put upon a red-hot brick, *Fig*. 183, it melts in its own water of crystallization, and, after a great quantity of steam is thrown off, a dry residue remains. Crystals often contain water in two different states, one portion known under the name of water of crystallization, which may generally be expelled by a moderate heat; another portion known as saline water, which is with much more difficulty driven off. In the works on chemistry, the formulæ are constructed so as to indicate these different conditions of the water: *Aq* (aqua) being the symbol for the water of crystallization, and *HO* for the saline water; thus,

Fig. 183.

$$FeO + SO_3 + HO + 6Aq,$$

is the symbol for green vitriol, which is therefore a sulphate of the protoxide of iron, with one atom of saline water and

---

How does water compare with other bodies as respects solvent power? What is meant by water of crystallization and saline water? How is this difference indicated in formulæ?

six of water of crystallization. The latter is easily driven off by heat, but the former only at high temperatures, or by being replaced by some other body.

Water unites with many acids with great energy. If mixed with sulphuric acid, and a thermometer immersed, the temperature will run up rapidly to above 212°. With basic bodies, the same results may be obtained as when quicklime is sprinkled with water, or potash and soda dissolved in it: toward acids water acts as a base; toward bases it acts as an acid; and toward salts as an indifferent body.

As found in nature, water is always impure. Rain-water and melted snow contain the various soluble gases which are in the air; spring, river, well, and mineral waters the soluble bodies of the strata through which they have flowed; from these it can only be purified by the process of distillation.

DEUTOXIDE OF HYDROGEN. $HO_2 = 17{\cdot}013$.

There is another compound of hydrogen and oxygen, the deutoxide of hydrogen. It contains twice the amount of oxygen found in water, and is characterized by a remarkable facility of decomposition. It is a liquid substance, possesses bleaching powers, and is heavier than water.

LECTURE XLIII.

NITROGEN.—*Preparation of Nitrogen.—Properties.—Its Indifferent Nature.—Its Oxygen Compounds.—Atmospheric Air.—Constitution of.—Dimensions of.—Relations to Organization.—Density and Temperature —Fixed and Variable Constituents.—Experimental Proofs of its Pressure.*

NITROGEN. $N = 14{\cdot}19$.

NITROGEN gas is most readily procured from the atmospheric air by burning phosphorus in a bell jar over the pneumatic trough. If a piece of phosphorus be laid in a cup

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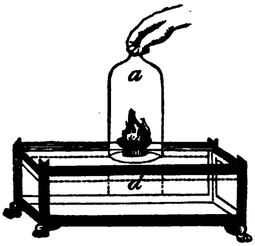
What is the relation of water to acids, bases, and salts? By what process is water purified? What is the constitution and properties of the deutoxide of hydrogen? What is the process for preparing nitrogen by phosphorus?

Fig. 184.



(*Fig.* 184) and set on fire, all the oxygen in the air of the jar, *a*, will be consumed, white flakes of phosphoric acid forming, and these being finally dissolved in the water of the trough, *d*, there is left behind nitrogen, contaminated to a small extent by the vapor of phosphorus.

If nitrate of ammonia be placed in a retort, and the temperature raised until it emits protoxide of nitrogen, and at that moment, by means of a wire passing through a cork in the tubulure, a piece of zinc is lowered down upon the melted mass, oxide of zinc is produced, and nitrogen gas escapes. The decomposition is very simple,

$$NO \,..\, Zn = Zn\ O \,..\, N.$$

Nitrogen gas is a colorless, tasteless, and inodorous body, very sparingly soluble in water, that liquid dissolving but 1½ per cent. of its volume. It is lighter than atmospheric air, its specific gravity being 0·976. Its atomic weight is 14·19. It does not support combustion nor respiration, and from the latter circumstance obtained formerly the name of azote; but it does not exert any directly poisonous agency on the animal system.

Nitrogen gas is little disposed to unite with other bodies, except when either it or they are in the nascent state. Its compounds, too, are prone to decompose from trivial causes; hence it is among them that we find some of the most remarkably detonating bodies. Many animal and vegetable substances, into the composition of which it enters, are characterized by the facility with which they tend to undergo putrefactive changes, and, as we shall hereafter find, ferments owe their remarkable powers to the presence of this element.

Nitrogen unites with oxygen, and forms five different bodies,

$$NO \ldots NO_2 \ldots NO_3 \ldots NO_4 \ldots NO_5.$$

Their names are

How may it be made from nitrate of ammonia? What are the properties of this gas? Why does it give rise to so many explosive bodies? To what is the property of ferments due? How many compounds of **oxygen and nitrogen** are there?

Protoxide of nitrogen. Deutoxide of nitrogen. Hyponitrous acid.	Nitrous acid. Nitric acid.

With oxygen, also, it forms atmospheric air; but this is a mixture, and not a compound.

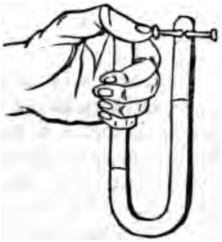
ATMOSPHERIC AIR.

The mechanical properties and constitution of the atmosphere are so important, that I shall here introduce the consideration of them before passing to the description of the oxides of nitrogen.

The atmosphere consists chiefly of oxygen and nitrogen gases, in the proportion of about 21 volumes of the former to 79 of the latter. It also contains a minute but essential quantity of carbonic acid, which, however, varies at different times, 10,000 parts of air containing, on an average, about five parts of this gas. Besides these, there are found in it variable quantities of the vapor of water, and traces of ammonia, sulphureted hydrogen, and carbureted hydrogen. It is a colorless, invisible, elastic substance, 815 times lighter than water, and is taken as the standard of comparison for the specific gravity of gases. Its specific gravity is, therefore, $=1{\cdot}000$. One hundred cubic inches of it weigh, at the mean temperature and pressure, very nearly 31 grs.

There are many methods by which the analysis of the air can be effected. Ure's eudiometer, *Fig.* 185, which consists of a siphon tube, closed at one end and open at the other, may be used for this purpose. Into the closed branch of the instrument, which is also graduated, a measured quantity of air is introduced, and to it is added an equal volume of hydrogen. The bend of the tube is occupied by water, as shown in the figure, a column of air intervening between this water and the open extremity of the tube. On this the thumb is closely pressed, as represented, and an electric spark passed through the instrument by the aid of its platina wires. This sets the gases on fire; the column of air beneath the thumb acting

Fig. 185.

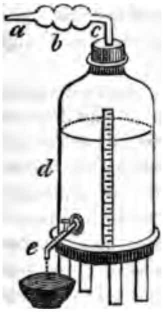


Of what is the atmospheric air composed? What is its specific gravity? What is the weight of 100 cubic inches of it? How may it be analyzed by Ure's eudiometer?

like a spring to repress the movement at the time of the explosion. The amount of gas then left is ascertained on the divisions, and one third of the deficit represents the quantity of oxygen originally present.

To enable the experimenter to operate on larger quantities of gas, Brunner's instrument may be used. It consists of a tube, *a b c*, with three bulbs blown upon it; these bulbs are filled with cotton which has been impregnated with melted phosphorus. The tube is attached, by means of a cork, to a glass vessel, *d*, filled with mercury. On opening the stop-cock, *e*, the mercury flows out, atmospheric air introducing itself by *a b c*, and its oxygen being removed by means of the extensive surface of phosphorus which the cotton presents. Consequently, by measuring the mercury which has flowed out, we ascertain the quantity of nitrogen introduced into the vessel *d*, and the increased weight of the tube *a b c* determines the amount of oxygen.

Fig. 186.



The result of such experiments shows that the atmospheric air is composed of from 20·79 to 21·08 parts of oxygen in 100 volumes. By weight, its constitution is about,

Oxygen	23·04
Nitrogen	76·96
	100·00

The earth's atmosphere does not extend indefinitely into space, but terminates at an altitude of about fifty miles. It forms, therefore, a mere film on the face of the earth, for the diameter of the globe is nearly 8000 miles. If a representation of it were placed on a common twelve-inch globe, it would scarcely be one eighth of an inch thick.

Its relations to the world of organization are full of interest. All plants come from it, and all animals return to it, so that it stands as the bond of connection between these orders of life.

As we ascend to more elevated regions the air becomes less dense, for the obvious reason that, as it is a very com-

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How may atmospheric air be analyzed by Brunner's instrument? **What is its constitution by volume and by weight? To what distance does it extend? What are its relations to animals and plants?**

pressible body, those portions of it nearest the ground have to sustain the weight of the superincumbent mass, and are therefore more dense; but in the higher regions, where the superincumbent pressure is less, the air is more rare, as is shown in the following table:

Height in Miles.	Volume of Air.	Barometric Inches.
0·	1	30·
2·705	2	15·
5.41	4	7·5
8·115	8	3·75
10·82	16	1·875
13·525	32	·9375
16.23	64	·46875

which also shows that the great mass of the atmosphere is comprehended within a very short distance of the earth's surface. At different altitudes it is of very different temperatures, being colder as the altitude is greater.

Of the constituents of the air, the oxygen and nitrogen are usually spoken of as fixed, the carbonic acid, ammonia, and water as variable. There are causes in operation which tend continually to impress changes in the amount of all these bodies. Every process of combustion, and the respiration of every animal, remove oxygen and replace it by carbonic acid. But the growth of plants has the reverse action, removing carbonic acid and replacing it by oxygen, so that for many centuries in succession the constitution of the atmosphere is unchanged.

Of the mechanical properties of the air, the first to which we have to direct our attention is its pressure, which takes effect equally in all directions, upward, downward, and laterally. Thus, if we take a glass tube several feet long, *a*, *Fig.* 187, closed at one end and open at the other, and having filled it full of water, place over the mouth of it a piece of card, *b*, and turn it upside down, the card will not fall off, nor the water flow out; they remain, as it were, suspended on nothing, but in reality sustained by the upward pressure of the air. Or if we take a bottle, *a*, *Fig.* 188, with a hole, *b*, half an inch in diameter, in the bottom of it, and having filled it with water, close the mouth

Fig. 187.

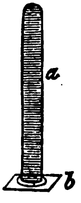
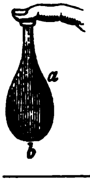


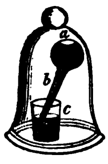
Fig. 188.



Why does its density decrease with the altitude? How does its temperature vary? Which are the fixed, and which the variable constituent of the air? Give some illustrations of the upward pressure of the air.

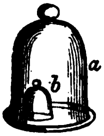
of it with the finger, it may be held up in the air without the water flowing out, although the aperture *b* is wide open. In this instance, again, it is the upward pressure of the air which sustains the liquid.

Fig. 189.



Let the glass globe *a*, *Fig.* 189, with its neck *b*, be inverted in some water contained in a jar, *c*, and the whole covered by an air-pump receiver. As the receiver is exhausted, bubbles of air pass through the water and escape away, but as soon as the pressure is restored, the water is forced out of the jar upward into the globe.

Fig. 190.



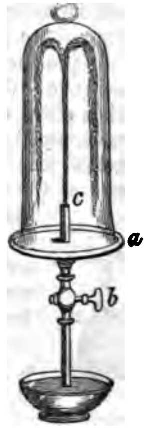
The air-pump enables us to exhibit in a very striking manner many of the chief mechanical properties of the atmosphere. Thus, if upon the plate of it there be placed a glass receiver, *a*, *Fig.* 190, as soon as the air is exhausted from its interior, the superincumbent pressure retains the glass so firmly in contact that it is impossible to lift it off, but as soon as the air is readmitted, it can be easily removed. If within the receiver *a* a smaller one, *b*, be placed, and exhaustion made, while *a* is fixed, *b* can be easily moved by shaking the pump, but on letting in the air, *a* becomes loose and *b* firmly pressed in contact with the plate.

Fig. 191.

If over the mouth of a jar, *Fig.* 191, placed upon the pump, the palm of the hand be laid, as the air is exhausted it is pressed in close contact with the jar, and can only be removed by the exertion of a very considerable force.

On a small plate, *a*, *Fig.* 192, furnished with a stop-cock, *b*, terminating in a fine jet, *c*, let there be placed a tall glass receiver. The stop-cock being now screwed into the pump and opened, the air may be exhausted from the interior of the receiver and the stop-cock closed. But being now opened under the surface of some water in a cup, the water passes through the jet and rises to the top of the jar, forming a fountain in vacuo.

Fig. 192.



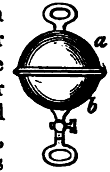
Give an illustration of its downward pressure. Describe the experiment *represented in Fig.* 191. Describe the fountain in vacuo.

LECTURE XLIV.

Atmospheric Air.—*Pressure of the Air.—Simple Means of Exhaustion.—Determination of the Weight of Air.—Amount of Pressure.—Elasticity of Air.—Exists in the Pores of Bodies.—Respiration of Fishes.—Measure of Elastic Force.*

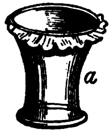
The Magdeburg hemispheres, invented by Otto Guericke, who also invented the air pump, illustrate in a very striking manner atmospheric pressure. They consist of a pair of brass hemispheres, *a b*, *Fig.* 193, with handles; they fit, without leakage, to each other by a flange, so as to form a perfect sphere. One of them has a stop-cock, through which the air may be exhausted, and on this being done, it will be found almost impossible to pull them apart, though as soon as the air is readmitted, and its pressure restored to the interior, they will fall asunder by their own weight.

Fig. 193.



If over the mouth of an open receiver, *a*, *Fig.* 194, a piece of bladder be tightly tied with a waxed thread, when the air is exhausted the bladder becomes deeply depressed into a spherical concavity by the superincumbent pressure, and finally bursts inward with a loud explosion.

Fig. 194.



It is upon the principle of atmospheric pressure that the various instruments used by surgeons for cupping act. One of the most simple methods of performing this operation is to place the cupping glass for a moment over the flame of a spirit lamp, and then transfer it rapidly to the skin. Spirits of wine, when burning, forms a very large quantity of steam, which of course fills the interior of the glass in a rarefied state by reason of the high temperature of the flame. As soon as this steam condenses a vacuum is formed, and the soft surface on which the cup is placed is pressed into its interior.

For many of these experiments an air pump is not nec-

What are the Magdeburg hemispheres? What is the principle illustrated in these various experiments? How is the process of cupping performed?

essarily required, but simple contrivances will answer in its stead. Thus, if we take an eight-ounce vial, *a*, *Fig.* 195, and fit to the mouth of it a cork, *b*, through which there passes a piece of glass tube, *c*, drawn into a narrow jet at one extremity, but open at the other, by placing the finger over the opening and introducing it into the mouth, the air, by the action of the tongue and the muscles of the mouth, may be sucked out to a great extent; and when the exhaustion has been carried, by this means, as far as possible, by pressing the finger over the opening, it will close it, acting, therefore, as a valve. And now, if the bottle be turned upside down, as at *e*, the tube dipping beneath some water in a cup, as soon as the finger is removed the water is pressed upward, and forms a fountain in vacuo.

Fig. 195.

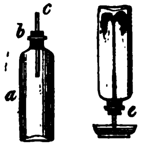
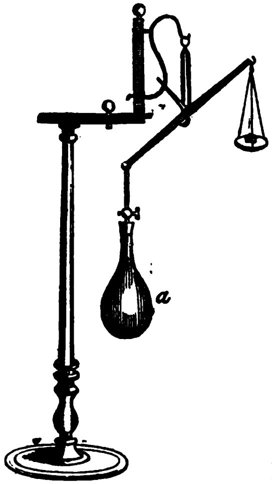


Fig. 196.



The pressure of the air depends primarily on the fact that it is a heavy body, as may be proved by the direct experiment of weighing it. For this purpose, let a light glass flask, *a*, *Fig.* 196, fitted with a stop-cock, be counterpoised at the balance; then let the air be exhausted from it, and its weight determined again. It will now be found lighter than before; but upon opening the stop-cock it will regain its original weight. Experiments made in this manner show that a flask containing 100 cubic inches will, when exhausted, weigh about thirty-one grains less, and therefore we infer that that is the weight of 100 cubic inches of atmospheric air.

Atmospheric air is used as the standard of comparison of the specific gravities of other gaseous bodies. The process for the determination is very simple. A glass globe, *g*, *Fig.* 197, holding 20 or 30 cubic inches, is exhausted of air,

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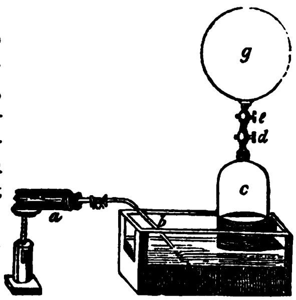
Describe a simple method by which partial exhaustion may be produced by the mouth. How may the weight of air be directly ascertained? In what manner may the relative weight of other gases be determined?

and by means of the stop-cocks, *e d*, attached to the jar, *c*, containing the gas to be tried. This gas, which is confined by mercury, has been passed through the drying tube, *a*, by the delivering tube, *b*, into the jar, which should be graduated. On opening the cocks, *e d*, the gas flows into the exhausted globe; the quantity introduced may be determined on the graduation, and its weight ascertained by the balance.

Fig. 197.

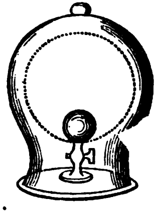


There are several different methods of stating the amount of the mean pressure of the air; thus we say that it is equal to 15 pounds on the square inch, or to a column of mercury 30 inches long, or to a column of water 30 feet long.

That air is a highly elastic substance can be readily shown. Under a receiver (*Fig.* 198) let there be placed a half-blown bladder, the neck of which is tightly tied; as the air is removed from the receiver the bladder distends, but on restoring the pressure it becomes as flaccid as it was before, showing that the air included in it expands and contracts as the pressure upon it is made to vary.

Fig. 198.

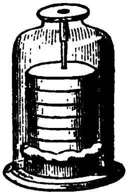
Fig. 199.



This may be still better shown by taking a small India-rubber bag (*Fig.* 199), the mouth of which is closed tightly, and using it instead of the bladder in the last experiment. On rarefying the air in the receiver, the bag begins to dilate, and may be extended to several times its original dimensions, as shown in the dotted line; but as soon as the pressure is restored, it returns to its original size.

Nor does this expansion take place with an inconsiderable force. If a flaccid bladder be placed, as in *Fig.* 200, with several heavy lead-

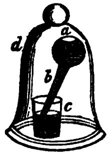
Fig. 200.



What is the pressure of the air on a square inch equal to? What is nearly the equivalent length of a mercurial and water column? How may the elasticity of air be illustrated? How may it be shown by an India-rubber bag? Give an illustration of the amount of this force.

en weights put upon it, as soon as it is caused to dilate by removing the pressure, it will push up the weights. Nor does it lose its elastic force or spring by being long pent up in close vessels. Some of the old chemists kept air compressed in copper globes for months, and found that, as soon as an opening was made for it, it expanded to its original dimensions.

Fig. 201.



Let there be taken a glass bulb, *a* (*Fig.* 201), the open neck of which, *b*, dips beneath some water in a jar, *c*, and let the bulb and tube be full of water, with the exception of a small space occupied by atmospheric air. On covering the apparatus with an air-pump receiver, *d*, and exhausting, the bubble of air, *a*, gradually expands, and after a time, as the action of the machine is continued, fills the entire glass, both bulb and tube; but as the pressure is restored, it contracts again, and goes back to its original size.

Fig. 202.

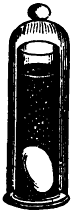


Fig. 203.

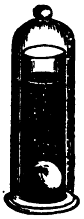


Fig. 204.

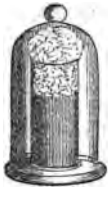
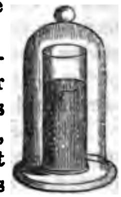


Fig. 205.



By taking advantage of the expansibility of air under reduction of pressure, we are able to demonstrate its existence in the pores of many bodies; thus, if we place in glasses of water an egg (*Fig.* 202), an apple (*Fig.* 203), or other such objects, and, covering them with a receiver, exhaust, we shall see innumerable bubbles of air escaping through the water. The same observation may be made in the case of many liquids which hold gaseous substances dissolved. A glass of ale placed in an exhausted receiver (*Fig.* 204) foams from the escape of carbonic acid gas, and even clear spring or river water, examined in the same manner (*Fig.* 205), is found to contain a large quantity of air in solution.

This last fact is of considerable importance, for it is by the aid of this air that the respiratory function of fishes is carried forward. On examination, however, it is found that this is not true atmospheric air, but a mixture, which is

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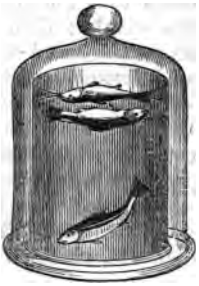
How may the presence of air be detected in the pores of solid bodies? How may air be shown to exist dissolved in liquids? **Of what use is the air dissolved in water?**

Fig. 206.



richer in oxygen. The atmosphere contains 21 per cent. of oxygen, but this gas contains 33. The cause of the difference is the unequal solubility of oxygen and nitrogen; for the former gas being much the more soluble, the water takes up relatively a greater portion of it from the air. Fishes, therefore, respire this gas, its richness in oxygen making up for its inferior amount; and when they are placed in water which has been in an exhausted receiver, they die. Their movements, also, are, to a certain extent, regulated by the air contained in a receptacle, or bladder, in their bodies; by the compression of it they can descend, and by its expansion rise. If they be placed in water in a partially exhausted receiver, they float on the surface, or can only descend to the bottom for a moment by violent muscular exertion.

The necessity of air to the support of combustion may be illustrated by comparing the length of time a candle will burn in a large receiver full of air, and in the same exhausted. In the latter case it speedily dies out, the smoke descending to the bottom of the jar in the rarefied medium around.

Fig. 207.

Substances prone to decay, such as meats and fruits, may be preserved for a length of time in vessels void of air. The process is illustrated in *Fig.* 207. The fruits are placed in a large jar closed by a sound cork, covered with sealing-wax. A small hole is made through the cork, and the jar covered by an air-pump receiver. On exhausting, the air passes out through the hole, and when the vacuum is perfect, the hole is closed by melting the wax by the sunbeams converged by a convex lens, the access of the air being thus cut off.

What is its **composition?** How may the necessity of air to the support of combustion **be proved?** By what means may objects be preserved from its **influence?**

From the foregoing experiments and considerations, it appears that the primary fact in pneumatics is, that the air has weight; from this, by a necessary consequence, arises its pressure and the inequality of density of the atmosphere at different altitudes. It also follows that the elastic force of the air must be precisely equal to the pressure upon it. In any given stratum of air, as, for instance, that which rests upon the surface of the earth, the pressure of the superincumbent mass is equipoised by the elastic force; if the elastic force were less, compression would ensue; if greater, dilatation. The pressure and the elastic force must, therefore, be equal to each other.

LECTURE XLV.

Atmospheric Air.—*The Barometer.—Description of it.—Cause of the Phenomenon.—Proof that it is the Pressure of the Air.—History of the Invention.—Paschal's Experiment.—Illustrations of the Nature of Pressure.—Variability of Pressure.—Point of Perpetual Congelation.—Local Disturbances in the Constitution of the Air.—Diffusion of Gases.—The Air is a Mixture.—Marriotte's Law.—Gay-Lussac's and Rudberg's Law.*

If we take a tube of glass, *a b*, *Fig.* 208, more than thirty inches long, closed at one end and open at the other end, and, having filled it with quicksilver, invert it in a cup, *c*, filled with that metal, the mercury will not flow out of the tube, but will remain suspended at a height of twenty-eight or thirty inches. If there be placed beside the tube a scale, *d*, divided into inches and decimal parts, the zero of the division coinciding with the level of the mercury in the cup, such an instrument forms the barometer.

Fig. 208.

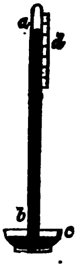
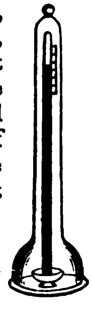


Fig. 209.



The cause of the suspension of the mercury in the tube is the pressure of the air. This may be demonstrated by placing over the barome-

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What is the relation between the pressure and the elastic force of the air? Describe the barometer. What is it which supports the mercurial column?

ter a tall air-pump receiver, and exhausting. It will be found that, as the pressure in the interior of the receiver is reduced, the column of mercury in the barometer falls, and on restoring the pressure, it rises to its original point.

The same fact may be proved in another manner. If a tube, upward of thirty inches long, the upper extremity of which is closed by a piece of bladder, be filled with mercury and inverted in a cup, as shown in *Fig.* 210, the bladder will be found deeply depressed, the pressure of the air in that direction being borne by it; but if now a minute pinhole is made in the bladder, so as to allow the air to press upon the top of the mercury, the column rapidly descends, flowing out of the tube.

Fig. 210.

The barometer was originally invented by Torricelli. Some plumbers, working for the Duke of Florence, found that it was impossible to make a pump which should raise water more than about thirty feet. This fact eventually coming to the knowledge of Torricelli, he suspected that the water rose in those machines in consequence of the pressure of the air, and not through Nature's abhorrence of a vacuum, as was at that time supposed. But if the limit to which water can be raised by a pump is reached when the pressure of the column of liquid equilibrates the pressure of the air, it follows that if a heavier fluid than water be used, the height to which it can be raised is less. A pump ought, therefore, to lift quicksilver only about as many inches as it can lift water feet; for the weight of these liquids is about as one to thirteen and a half; and, accordingly, Torricelli found, by means of a small pump fixed to a long glass tube, that such, in reality, is the case. The barometer is a simplification of the same apparatus.

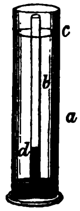
That it is the pressure of the air which sustains the mercurial column was satisfactorily proved by Paschal, who reasoned that, if this were the case, the barometric column ought to be shorter on the top of a mountain than in a valley, because in the former position that pressure must necessarily be less. On the experiment being made, his reasoning was found to be true.

The principle of the barometer may be illustrated by sub-

How may this be proved? By whom was the barometer invented? What were the circumstances of the invention? What was Paschal's experiment? What did it prove?

stituting for the pressure of air the pressure of a column of water. Thus, if we pour some quicksilver into the bottom of a deep glass jar, *a*, *Fig.* 211, and plunge into it a long tube, *b*, open at both ends, the quicksilver will rise in this tube, so that its level on the inside will be coincident with that on the outside. But if now we begin to fill the jar with water, *c*, for every thirteen and a half inches in depth poured in, the quicksilver, *d*, will rise one inch, the mercurial column counterpoising the column of water. And, on the same principle, the column of quicksilver in the barometer counterpoises that of the air to the top of the atmosphere.

Fig. 211.



Mr. Boyle discovered that the pressure of the air is not always the same, but it undergoes many variations, the mercurial column sometimes falling near to 27 inches, or rising above 30. The range is commonly estimated at 2·5 inches. It is considerably less in the tropics. These changes of pressure are exceedingly irregular, and are connected with meteorological phenomena. There are also diurnal variations, the column rising twice in the twenty-four hours. In winter the first maximum is about nine A.M., and the minimum at three P.M., the second maximum being about nine P.M.

It has already been observed that the mean pressure of the air is estimated at 15 pounds upon a square inch, or equal to a column 30 inches long. A man of average size sustains a pressure on the surface of his body of nearly thirty thousand pounds.

The temperature of the atmosphere is lower as we ascend to more elevated regions. A point, therefore, can always be reached over any place of which the temperature never rises over 32° F., and where water is always frozen. This point is known under the name of the point of perpetual congelation. Its altitude differs very much in different places, being highest at the equator, and lower as we go toward the poles. It is at

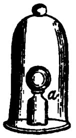
The Equator	15,000 feet.
Latitude 40°	9,000 "
" 75°	1,000 "
" 85°	117 "

How may the phenomena of the barometer be illustrated by the pressure of a water column? What is the extent of the irregular variations of pressure? What are the diurnal variations? At what times do the maxima and minima occur? What is the point of perpetual congelation? How does it vary with the latitude?

Many causes conspire to give rise to local disturbances in the constitution of the air. In its lower strata combustion and respiration are actively going on; they tend to diminish the oxygen and increase the carbonic acid. At the equator the effect of a constantly brilliant sunshine on the leaves of plants is to diminish the carbonic acid and increase the oxygen. But notwithstanding these local disturbances, and also the fact that the constituents of the air are of very different specific gravities, the constitution of the atmosphere is nearly the same in all places. This commixture is partly effected by the mechanical action of winds, and partly by the property which gases have of diffusing into each other. Thus, if two vials, *a* and *e*, *Fig.* 212, communicate with each other by means of stop-cocks, *b c d*, and if, in *a*, a light gas, such as hydrogen, is placed, and in *e* a heavy gas, as carbonic acid, in a few minutes after the stop-cocks are opened the gases will diffuse into each other, the light one descending and the heavy one ascending, until they are perfectly commixed. And this effect will take place even though a barrier should intervene. Thus Dr. Mitchell found that gases would readily pass through the close texture of India-rubber to mingle with each other; and I have observed the same in the case of films of water. Thus, if a bottle, *a*, *Fig.* 213, full of atmospheric air, have its mouth closed by a film of soap-water spread over it by the finger, and then be placed under a bell jar containing protoxide of nitrogen, this latter gas passes rapidly through the film, and distends it into a bubble by forcing its way into the bottle. The force with which gases will thus pass into each other is sometimes very great. I have proved that sulphureted hydrogen will diffuse into atmospheric air, though resisted by a pressure of more than fifty atmospheres.

Fig. 212.

Fig. 213.



That the atmospheric air is a mixture, and not a compound, is proved by its easy decomposibility, its refractive power, and by the fact that its constituents retain their properties unchanged. The amount of its oxygen may be de-

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What are the causes which tend to change the composition of the air? What is meant by the diffusion of gases? Does this take place through intervening barriers? How is this connected with the constitution of the air? What proofs are there that the atmosphere is a mixture, and not a compound?

termined by the combustion of phosphorus, or detonation with hydrogen; the amount of its carbonic acid, which varies in damp or dry seasons, being dissolved out by showers of rain, may be determined by potash or lime-water, and its aqueous vapor by the process for the dew-point already described.

Fig. 214.

Atmospheric air being thus an elastic and compressible body, it remains to explain the law which determines its volume under changes of pressure. This is known under the name of the law of Marriotte, and, applying to many other gases besides atmospheric air, is to the effect *that the volume of a gas is inversely as the pressure upon it.* This law is of the utmost importance in gaseous chemistry. It may be illustrated by the instrument (*Fig.* 214), where *a b* is a bent tube, open at the end *a*, and closed at *b*. The branch *a* may be several feet long, and *b* six inches. A small quantity of mercury is poured into the tube, so as to occupy the bend and shut up a column of air between *d* and *b*. Now, if the tube is filled with quicksilver to the height of 30 inches, as to *a*, the pressure of this column is exerted on the air in the closed branch, *b;* and as there are now the weight of two atmospheres, that of the ordinary atmosphere and that of the mercurial column, it is compressed into half its former volume, *c*. If we bring upon it three atmospheres, it will be compressed into one third; if four, to one fourth, &c. And the law holds good, also, for diminutions of pressure. If, on a given volume of gas, the pressure is reduced to one half, the volume doubles; if to one third, it triples; to one fourth, it quadruples; in all cases the volume being inversely as the pressure.

The exact amount of dilatation of atmospheric air for elevations of temperature was determined by Gay-Lussac as follows: In a tin box, A (*Fig.* 215), containing water, there is introduced through a perforation at *o′* a bulb, *g*, with a tube, *g′*, containing the air, the dilatation of which is to be measured. This air has been previously introduced in a state of dryness by the chloride of calcium tube, *h h′*. At *m* is a globule of mercury, which acts as an index, and confines the air. On the opposite side of the tin box, at *o*, a thermometer, *s t b*, is introduced, and another one, *v*, passing

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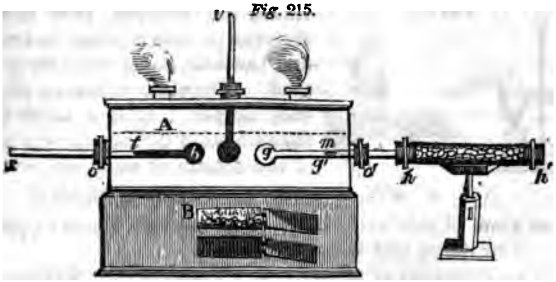
What is Marriotte's law? How may its truth be proved? Give examples of Marriotte's law. What is the law of Gay-Lussac?

Fig. 215.



through the top of the box, occupies the center. The box is first filled with water containing fragments of ice, and when the thermometers are at 32°, the position of the index, *m*, is marked. The furnace is then lighted, and when the water boils, and the thermometers are at 212°, the index, *m*, is again observed. The difference indicates the dilatation of the air for 180°; and in this manner Gay-Lussac found that 100 volumes of air become 1375. These results have been of late carefully examined by Rudberg, who fixes the amount of expansion of air at $\frac{1}{493}$ of its volume, at 32°, for every degree of Fahrenheit's scale.

LECTURE XLVI.

COMPOUNDS OF NITROGEN AND OXYGEN.—*Protoxide of Nitrogen.—Preparation and Properties of.—Constitution.—Supports Combustion.—Produces Intoxication. Deutoxide of Nitrogen.—Preparation and Properties of.—Constitution.—Relations to free Oxygen.—Hyponitric Acid.—Preparation and Properties of.*

PROTOXIDE OF NITROGEN. $NO = 22{\cdot}203$.

IF the nitrate of ammonia be exposed to a temperature of about 350 degrees in a retort, *Fig.* 216, it undergoes decomposition, being resolved into water and the protoxide of nitrogen; the former condensing in the neck of the retort, and the latter rising into the pneumatic jar. If whitish

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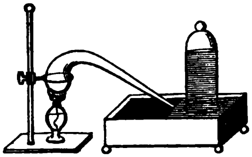
What is the absolute dilatation of air as determined by Rudberg? How may protoxide of nitrogen be made?

Fig. 216.



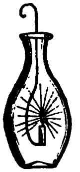
fumes are evolved, they indicate that the process is going on too fast, and the heat must then be moderated. The change taking place is very simple. It is a mere re-arrangement of the constituent atoms of the nitrate of ammonia.

$$NO_5 + NH_3 \ldots = \ldots 2(NO) + 3(HO).$$

One atom of that salt, therefore, yields two atoms of protoxide of nitrogen and three of water.

The protoxide of nitrogen is a colorless gas, transparent, like atmospheric air; it has a sweetish taste, and is soluble in water, that liquid taking up about three fourths of its volume of the gas when cold, but the solvent power being greatly diminished by warming the water. Its specific gravity is 1·527. It may be liquefied at 45° by a pressure of fifty atmospheres, and has even been solidified. In the liquid form it is colorless, and boils at —125°. A drop of it falling on the skin produces, as it were, a burn. Water put in contact with it instantly freezes. If the liquid be permitted to escape into the air from a jet, a part of it instantly freezes into a snowy solid. It is composed, by atom, of one of nitrogen and one of oxygen, and by volume, of two volumes of nitrogen united to one of oxygen, condensed into two volumes, a constitution like that of water. It therefore contains half its bulk of oxygen gas, and supports combustion with activity. A lighted taper immersed in it burns brightly, and, as in oxygen, if there be merely a spark on the wick, it kindles into a flame. Phosphorus burns in it with great brilliancy.

Fig. 217.



Sir H. Davy discovered that not only does this gas support respiration, but that it exerts a remarkable physiological action when breathed, producing a transient intoxication, which wears off after two or three minutes. These effects are undoubtedly due to the oxydizing action which the protoxide establishes in the system. In this respect it is far more active than even pure oxygen gas, and the reason is obvious: oxygen is but slightly absorbable by watery fluids, but this gas is taken up by them to a very great ex-

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What are the properties of protoxide of nitrogen? What is its constitution? Does it support combustion? What are its relations to respiration? How long does this intoxicating effect last? What is the cause of it?

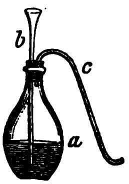
tent. When it is introduced into the lungs, it is rapidly dissolved in the blood, and carried by the circulation to every part of the body, oxydizing whatever is in its path, and producing a febrile warmth and an unusual mental disturbance.

The protoxide of nitrogen shows but little disposition to unite with other bodies. It may be regarded as an indifferent substance.

DEUTOXIDE OF NITROGEN. $NO_2 = 30·216$.

The deutoxide or binoxide of nitrogen may be made by the action of nitric acid moderately diluted upon metallic copper. If these substances are introduced into a flask together, and, when the action moderates, fresh portions of nitric acid be added through the funnel (*Fig.* 218), a colorless gas is evolved, which may be collected over water, in which it is only sparingly soluble, one hundred volumes of that liquid dissolving about five of the gas.

Fig. 218.



It is composed of equal volumes of nitrogen and oxygen united, without condensation. Its specific gravity is, therefore, 1·0416. It does not support combustion; a lighted taper immersed in it is at once extinguished; but if phosphorus, burning violently, be introduced in it, the combustion goes on with increased activity. Iron and several other metals withdraw from it one half of its oxygen, converting it into the protoxide.

The most remarkable quality of the deutoxide of nitrogen is its action on mixtures containing oxygen gas, as, for example, atmospheric air; with these it at once produces red fumes of nitrous acid, which are soon removed if water be present, the deutoxide taking up two atoms of oxygen to change into nitrous acid. On this principle it has been used for the purpose of effecting the analysis of atmospheric air, but, unless several precautions are observed, the results are incorrect. The deutoxide should be added in a small and steady stream to the air; red fumes are at once produced; these are soon removed by the water, and the residue is less in volume than the air and deutoxide taken together. One fourth of the deficit is equal to the volume of the oxygen

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Why is the protoxide of nitrogen an indifferent substance? How is the deutoxide obtained? What is its constitution? Does it support combustion? What is its action on gaseous mixtures containing oxygen? Under what circumstances may it be used to determine the amount of oxygen?

originally present. By operating in this manner, as I have had many occasions to observe, correct results may be obtained The general process may be illustrated by taking a tall jar and placing in it a certain volume of atmospheric air, to which is to be added an equal volume of the deutoxide. Though both gases are colorless at first, a deep copper-colored vapor is the result; this is removed after a time by the action of the water, which, rising in the jar, exhibits a deficit in the amount of the gases.

A solution of the protosulphate of iron dissolves this gas abundantly; and if a small quantity of the sulphuret of carbon be poured into it, and a light applied, the mixture burns with a blue flame.

HYPONITROUS ACID. $NO_3 = 38{\cdot}229$.

This substance may be made by mixing four volumes of dry deutoxide of nitrogen with one of dry oxygen, and exposing the mixture to cold. The gases condense into a liquid of a greenish color, which gives forth an orange vapor. Hyponitrous acid is decomposed by the contact of water, deutoxide of nitrogen escaping with an effervescence, and nitric acid being produced, three atoms of hyponitrous acid yielding one of nitric acid and two of the deutoxide.

$$3NO_3 \ldots = \ldots NO_5 + 2NO_2.$$

LECTURE XLVII.

COMPOUNDS OF NITROGEN AND OXYGEN.—*Nitrous Acid.—Preparation and Properties of.—Remarkable Changes of Color.—Nitric Acid.—Discovery of.—Cavendish's Experiments.—Sources from which it is derived.—Commercial Preparations.—Its Properties.—Is a Hypothetical Body.—Purification.—Detection.*

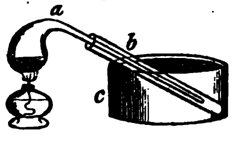
NITROUS ACID. $NO_4 = 46{\cdot}242$.

NITROUS acid may be made by mixing together one volume of dry oxygen with two of the dry deutoxide of nitrogen, and exposing the mixture to a very low temperature;

How may the action of deutoxide of nitrogen on oxygen mixtures be illustrated? What is its relation with the protosulphate of iron? And what with the vapor of sulphuret of carbon? How may hyponitrous acid be procured? What is the action of water on it? How may nitrous acid be made?

but it is much more easily procured by distilling, in a porcelain or hard glass retort, *a*, *Fig.* 219, dry nitrate of lead, and receiving the gases in a tube, *b*, artificially cooled by a freezing mixture, *c*. The nitrous acid condenses as a colorless liquid, which becomes yellow as its temperature rises. Its specific gravity, in the liquid form, is 1·42. It solidifies at 40° F., and boils at 82° F. Its vapor possesses remarkable optical qualities. When its temperature is very low, it is nearly colorless; it takes on an orange tint as the degree of heat increases, and finally becomes almost black. The peculiarity of the phenomenon is, that if the gas be examined while undergoing these changes, by passing a ray of light through it and analyzing it by means of a prism, as explained in Lecture XX., a great number of fixed lines are found in the resulting spectrum; and as the temperature rises, these increase so much in number and in breadth that the light becomes finally obliterated.

Fig. 219.



The vapor of nitrous acid, when once mixed with atmospheric air, is condensed into the liquid form with great difficulty. It is wholly irrespirable, and, even when diluted, of a very unpleasant odor. Nitrous acid is, for the most part, decomposed by water,

$$3NO_4 \ldots = \ldots 2NO_5 + NO_2,$$

three atoms of it yielding to two of nitric acid and one of the deutoxide of nitrogen, as seen in the formula; but the nitric acid produced protects a portion of the nitrous acid, which thus escapes decomposition. Its vapor is absorbed by nitric acid. The production of this acid by the process with nitrate of lead is of considerable philosophical interest;

$$PbO + NO_5 \ldots = \ldots PbO + NO_4 + O,$$

one atom of the nitrate of lead yielding one atom of oxide of lead, which remains in the retort, one of nitrous acid, and one of oxygen gas, which escape. It might be expected that, in such a distillation, we should obtain oxide of lead and nitric acid. The cause of the non-appearance of the latter body will, however, be presently understood.

What are its properties? How does the color of its vapor change by heat? What is the cause of the final blackness? What are the relations of nitrous acid and water? What is the decomposition which takes place when nitrate of lead is distilled?

NITRIC ACID. $NO_5 = 54{\cdot}255$.

Nitric acid, the most important of the compounds of oxygen and nitrogen, and one of the most important of the acid bodies, was first discovered during the ninth century. The discovery of this and some of the other powerful acids form one of the epochs in chemistry. The science can scarcely be said to have existed until that time, the Egyptians, Greeks, and Romans having no knowledge of these bodies, nor, indeed, of any more powerful than vinegar.

The constitution of nitric acid was determined by Mr. Cavendish, who formed it synthetically by passing electric sparks through atmospheric air in contact with a solution of potash. The nitrate of potash was obtained.

Nitric acid also occurs to a small extent in rain water, especially after thunder storms, and by some supposed to originate upon the same principles as in Cavendish's experiments; but probably it is due to the oxydation of ammonia, which always exists in the air. The chief supply is derived indirectly from the decay of vegetable or animal matter, in the presence of oxygen gas, and in contact with basic bodies. Collections of such refuse pass under the name of nitre beds, and, in France and Germany, furnish the saltpetre which is used for the manufacture of gunpowder. In the East Indies, nitrate of potash is obtained by lixiviation from the soil in which earthy nitrates naturally occur. From South America the nitrate of soda is exported; it is found as an efflorescence on soils in which common salt probably exists.

In most of these cases the nitric acid arises from the oxydation of ammonia produced during putrefactive fermentation.

$$NH_3 + O_8 \ldots = \ldots NO_5 + 3HO.$$

The formula shows the probable nature of the action; one atom of ammonia, under the influence of eight of oxygen, will yield one of nitric acid and three of water.

The nitric acid of commerce is made by distilling equal weights of sulphuric acid and nitrate of potash. The process may be conducted in a small way in a glass retort, A, *Fig.* 220; and it is found advantageous to use the quantity

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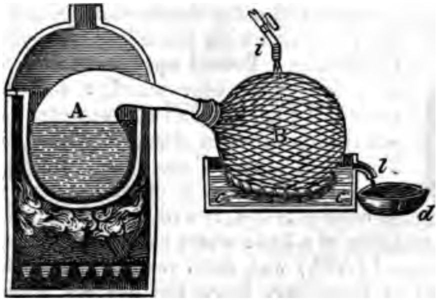
When was nitric acid discovered? How was its composition determined by Cavendish? What is the source of the nitric acid in rain water? From what sources is nitrate of potash produced? How may nitric acid arise from the oxydation of ammonia? How may nitric acid be made?

Fig. 220.



of sulphuric acid here stated, because a soluble bisulphate of potash is formed, which may be easily removed without breaking the retort. Half as much sulphuric acid would effect the decomposition, but it would require a higher temperature, and the neutral sulphate which forms could with difficulty be removed. The change which takes place is thus exhibited:

$$(KO,\ NO_5) + 2(HO,\ SO_3) \ldots = \ldots (KO,\ HO,\ 2SO_3) + (HO,\ NO_5;)$$

that is, one atom of nitrate of potash and two of sulphuric acid furnish one atom of bisulphate of potash, and one of hydrated nitric acid distills over into the receiver, B, which is kept cool by a stream of water flowing from *i* into a vessel, *c c*, the waste water passing through *l e d*. A net is wrapped over the receiver to distribute the water evenly. In this process nitrate of soda may be advantageously substituted for nitrate of potash.

Hydrated nitric acid thus produced is a colorless liquid, which boils at 248° F., though this point changes with the amount of water in the acid. It freezes at —40°; is decomposed into oxygen and nitrogen by being passed through a red-hot glass tube. It turns yellow in the sunshine, owing to a portion being decomposed and nitrous acid set free, which dissolves in the residue, and gives it an orange tint. The nitric acid of the shops (aqua fortis) commonly possesses this color, from which it may be freed by boiling in a glass vessel. It stains the skin and other organic matters

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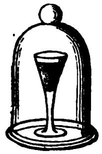
What are its properties? When passed through a red-hot tube, what happens to it? Why is commercial nitric acid often yellow? What is the action of this acid on the skin and on metallic bodies?

yellow, and hence is used in the arts of dyeing. Its action on many metalline and other combustible bodies is exceedingly violent, owing to the great amount of oxygen it contains. Poured upon some pieces of copper in a wine-glass, over which a bell jar may be inverted (*Fig.* 221), an effervescence takes place, and the red fumes of nitrous acid abundantly form. Though it is one of the most powerful oxydizing agents we possess, it often happens that, in a state of great concentration, it will scarcely act on a metal, but the addition of a little water causes the action to set in.

Fig. 221.



Nitric acid (NO_5) was, until recently, regarded as a hypothetical or imaginary body, the nearest approach to it being the strongest aqua fortis; this has a specific gravity of 1·521, and consists of one atom of hypothetical nitric acid and one of water. Its formula, therefore, is

$$NO_5+HO.$$

Its molecular constitution probably is

$$NO_6+H.$$

It is, as we shall find hereafter, a hydrogen acid. But M. Deville has shown that the anhydrous acid may be prepared by the action of chlorine or dry nitrate of silver. It presents the form of colorless crystals, which melt at about 85°, the boiling point being 113°, and gradually decomposes at ordinary temperatures.

Nitric acid of commerce can be purified by distillation, rejecting the first portions which come over, as they contain chlorine, and leaving a portion in the retort containing sulphuric acid and fixed impurities. If twelve parts are distilled, the first three may be cast aside, and one left in the retort; the intermediate eight are pure.

When it is in a solution, nitric acid may be detected by the addition of sulphuric acid, and a drop or two of protosulphate of iron; a brownish color is produced where the two liquids meet. When in a concentrated state, the evolution of red fumes, by the action of copper, detects it. It also gives a blood-red color with morphia. The nitrates deflagrate when ignited with combustible matter, a result which may be well shown by grinding together a few ounces of nitrate of potash and common sugar, and setting

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What is the nearest approach to hypothetical nitric acid? Why can not it be isolated? How may it be purified? How may it be detected?

fire to the mixture. Owing to the solubility of all its compounds, nitric acid can not be precipitated.

LECTURE XLVIII.

SULPHUR.—*Natural and Artificial Forms.—Preparation of Flowers.—Properties of Sulphur.—Its Vapor.—Oxygen Compounds of Sulphur.—Sulphurous Acid.—Preparation.—Properties.—Bleaching Effects.—Condensation to the Liquid State.—Its Compounds.*

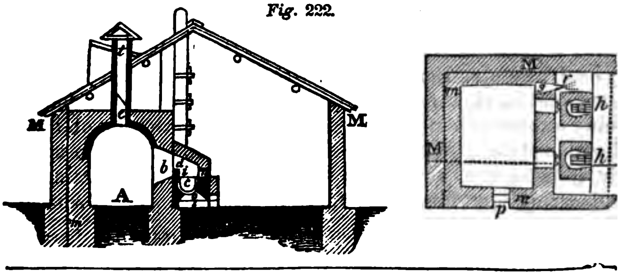
SULPHUR. S=16·12.

MUCH of the sulphur in commerce is derived from volcanic countries, in which it occurs often in a pure and crystallized state. It is one of the most common elementary substances, being found abundantly united with various metals, such as iron, copper, lead. In combination with lime, baryta, &c., it occurs as sulphuric acid, and is also an ingredient of many animal and vegetable products.

Sulphur is met with under three different forms: roll sulphur, flowers of sulphur, and lac sulphuris. Roll sulphur is an impure variety, which receives its form from being cast into cylindrical moulds; the flowers of sulphur are formed from the impure brimstone by sublimation; lac sulphuris differs from the foregoing in being of a white color. It is prepared by precipitation from the persulphuret of potassium by hydrochloric acid.

The preparation of flowers of sulphur is conducted in an apparatus, such as *Fig.* 222. A is a room, or chamber, of

Fig. 222.



Why can not nitric acid be detected by precipitation? Under what forms does sulphur naturally occur? What are its artificial forms? How are the flowers of sulphur made?

2000 feet capacity; *c* is a pan containing sulphur, which is melted by the furnace, *o s*; the vapor passes along *i d b*, and, entering the chamber, is there condensed. The resulting flowers are removed through the door *p*. If an explosion occurs, when the process commences, it lifts the valve *e*, and the gases escape through the chimney, *t*. *M M* is a shed under which the apparatus is constructed. As the iron pan becomes exhausted, new quantities of brimstone can be introduced through the door *n*.

Sulphur commonly exists as a solid of a yellow color, and of a specific gravity of 1·99, having neither taste nor smell. It melts at 226° F. into a pale yellow-colored liquid; but, what is very curious, if the heat be raised to about 450° F., it changes to the color of molasses, and becomes so thick and tenacious that the capsule in which the fusion is carried on may be turned upside down without the sulphur flowing out. At 600° F. it boils, and, as the heat approaches that point, it again becomes fluid; and, as it cools, runs through the same changes again in a reverse order. If suddenly quenched in cold water at the low temperature, before it thickens, it solidifies into ordinary sulphur; but if heated for a time to near 600°, and then quenched, it becomes, on cooling, elastic, like India-rubber, and may be drawn into long threads; and in this state is sometimes used for taking casts of coins, for by keeping a few days it slowly returns to the condition of ordinary sulphur.

When rubbed on a piece of flannel it becomes highly electric, assuming the negative state, and at one time was used in the making of electrical machines, before the powers of glass were discovered. A roll of it held in the warm hand emits a crackling sound, the crystals of which it is composed separating from one another. It is a bad conductor of heat and electricity, crystallizes under two different systems, and is, therefore, a dimorphous body, one of its forms being an acute rhombic octahedron, and the other an oblique rhombic prism. When heated to about 300° F. in the open air, it takes fire, and burns with a blue flame, emitting a suffocating odor, fumes of sulphurous acid gas. It is wholly

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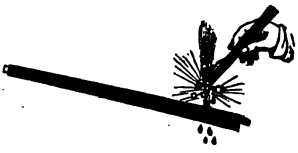
What are the properties of sulphur? What changes may be observed in it when melting? What electrical condition does it assume by friction? What are its conducting powers? Why is it called a dimorphous body? At what temperature does it take fire, and what is the product of its combustion?

insoluble in water; its proper solvent is the bisulphuret of carbon.

The vapor of sulphur is of a deep yellow color, and has the high specific gravity of 6·648. In it metallic bodies will burn precisely as they do in oxygen gas. Dr. Hare has shown that if a gun barrel be heated red hot at the breech, and a piece of sulphur dropped into it, the muzzle being closed with a cork, an ignited jet of sulphur vapor issues from the touch-hole, in which, if a bunch of iron wire be held, it takes fire and burns brilliantly.

Fig. 223.



Sulphur has a very extensive range of affinities, uniting with most metallic substances in several different proportions, with hydrogen and also with oxygen. With the latter substance it furnishes the following compounds:

$$SO_2 \,..\, SO_3 \,..\, S_2O_2 \,..\, S_2O_5 \,..\, S_3O_5 \,..\, S_4O_5;$$

their designations are, respectively,

Sulphurous acid.
Sulphuric acid.
Hyposulphurous acid.
Hyposulphuric acid.
Sulphureted hyposulphuric acid (acid of Langlois).
Bisulphureted hyposulphuric acid (acid of Fordos and Gelis).

SULPHUROUS ACID. $SO_2 = 32{\cdot}146$.

This acid may be formed by burning sulphur in oxygen gas or in atmospheric air; in the latter instance the resulting gas is, of course, contaminated with nitrogen. The process may be conducted under a bell jar, the burning sulphur being placed on a capsule or stand.

Fig. 224.

But a much better process is to effect the partial deoxydation of sulphuric acid by heating oil of vitriol with mercury, which deprives it of one atom of oxygen, forming an oxide of mercury, which unites with one atom of the excess of sulphuric acid present to form a sulphate. For many of the ordinary purposes to which sulphurous acid is applied, it may be procured by the action of fragments of charcoal heated with sulphuric

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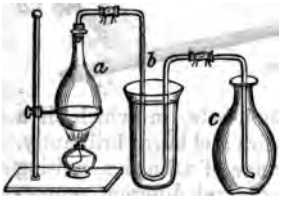
What is the specific gravity of its vapor? Does it support combustion? What are the oxygen compounds of sulphur? How may sulphurous acid be made? What is the principle of the process when sulphuric acid acts on mercury or charcoal?

acid. In this case, however, carbonic acid is also evolved. When a solution in water is required, the gas may be passed directly into that liquid, but if it be necessary to retain it in a gaseous state, it must be received in jars at the mercurial trough, or collected by the method of displacement.

Fig. 225.



It is, under the ordinary circumstances, a transparent and colorless gas, having an unpleasant taste, and the smell characteristic of burning sulphur. It is wholly irrespirable, and promptly extinguishes a lighted taper. Its specific gravity is 2·222, and, therefore, if a stream of it which has been cooled by flowing from the generating flask *a*, *Fig.* 225, through a bent tube, *b*, immersed in a jar of cold water, be conducted to the bottom of another jar, *c*, the gas, as it collects, displaces the atmospheric air, floating it out of the vessel. This process is of very general application in the collection of gases which are absorbable by water, and is known under the name of the method by displacement.

Fig. 226.

In a jar of sulphurous acid thus collected, if a lighted taper be immersed, it is at once extinguished. If the jar be inverted over water, the gas is speedily dissolved, that liquid taking up about thirty-seven times its volume of the gas. If vegetable colors are submitted to its influence, they are bleached, but the color is not destroyed as in bleaching by chlorine, since it can be restored by the action of a stronger acid.

Sulphurous acid is among the gases one that most readily takes the liquid form. If there be connected with the flask from which this gas is being evolved a bent tube passing through iced water in a jar, and the gas, after traversing this tube, be conducted into a bottle placed in a freezing mixture of snow and dilute nitric acid, it condenses into a colorless fluid of the specific gravity 1·45, which boils at 14° F. This fluid is sometimes used to produce intense cold by its evaporation.

What are the products in each case? Why must the gas be collected over mercury? What are its properties? What is the method by displacement? To what extent is this acid soluble in water? Are its bleaching effects permanent? How may it be condensed?

With bases, this acid forms a complete series of salts, the sulphites, which are readily decomposed by the stronger acids, and are occasionally employed as deoxydizing agents, from the circumstance that metallic oxides may be reduced by them, their sulphurous passing into the condition of sulphuric acid.

LECTURE XLIX.

COMPOUNDS OF SULPHUR AND OXYGEN.—*Sulphuric Acid.—The Anhydrous Acid.—Its Affinity for Water.—German Oil of Vitriol.—Its Constitution and Uses.—Common Sulphuric Acid.—Preparation on the large Scale.—Its Chemical Relations.—Purification.—Detection.—Other Sulphuric Acids.*

SULPHURIC ACID. $SO_3 = 40{\cdot}159$.

THIS compound is not alone the most important of the acids of sulphur, but also the most important of all acids. By the aid of it, nitric, hydrochloric, and many other strong acids are made for commercial purposes. In the production of carbonate of soda and chloride of lime, immense quantities of it are consumed.

Of sulphuric acid we have several varieties, differing from each other in the amount of water they contain. 1st. There is anhydrous sulphuric acid, the formula for which has already been given as containing one atom of sulphur and three of oxygen. This substance may be prepared by submitting the fuming oil of vitriol of Nordhausen to a temperature of about 290° Fahr., when there distills over a white substance of a crystalline aspect. It fumes in the air, melts at 77° Fahr., is converted into vapor at 160°, has an intense affinity for water, in which, if it be placed, it hisses like a red-hot iron. It is to be particularly remarked, however, that the acid powers of this substance are very feebly marked; it shows little tendency to unite with other bodies, and when such combinations are effected, the resulting sub stances are different from the true sulphates.

What are the properties of this liquid? For what purposes are the sulphites employed? What are the properties of anhydrous sulphuric acid, and how is it prepared?

2d. German, or Nordhausen oil of vitriol, $HO, SO_3 + SO_3$.

This substance is prepared by taking green vitriol, and, by exposure to heat, driving off its water of crystallization (six atoms), and also a portion of its saline water. If the dried powder be placed in a stone-ware retort and exposed to a high temperature, there distills over a dark oily liquid; hence the term *oil of vitriol:* this is the substance in question. Its formula shows that it is composed of two atoms of anhydrous acid united to one of water. A considerable quantity of it is used in the arts for dissolving indigo.

3d. Common sulphuric acid, HO, SO_3.

This is the substance which passes in commerce as common oil of vitriol. It is made on the large scale by burning sulphur with nitrate of potash or soda, and conducting the sulphurous and nitrous acids which result into large chambers lined with lead, in which steam is thrown, the bottom of the chamber being covered with water. The sulphurous acid takes oxygen from the nitrous acid, reducing it to the condition of deutoxide; but this being done in the presence of atmospheric air, which fills the chamber, the deutoxide instantly reassumes the condition of nitrous acid. The deutoxide, therefore, continually transfers oxygen from the atmospheric air to the sulphurous acid, and brings it to the condition of sulphuric acid.

After a time, the water at the bottom of the chamber becomes charged with sulphuric acid; it is then concentrated by drawing off the excess of water in platina or glass boilers, and finally assumes the specific gravity 1·845. It is a dense oily liquid, freezes at —15°, and boils at 620°.

Fig. 227.

The attraction of common sulphuric acid for water is very intense. If a tube, containing some ether, be stirred in a glass (*Fig.* 227) in which sulphuric acid and water are being mixed, the temperature rises so high that in a few moments the ether boils. On the same principle, it will remove from most gases which are passed over it any water they may contain; and, as we have seen in Lecture XII., water may be frozen by taking advantage of the rapidity with

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What is the process for preparing the German oil of vitriol? What is its appearance? For what purpose is it used? What is the process for preparing commercial sulphuric acid? What are its properties? What illustrations may be given of its intense affinity for water?

which sulphuric acid will absorb its vapor. Organic substances may also be charred by the action of this acid; for example, woody fibre is a compound of carbon with the elements of water, and when acted upon by sulphuric acid, the carbon is set free, the acid taking from it a portion of its water.

Sulphuric acid of commerce is never pure; it contains sulphate of lead, derived in the process of its manufacture, and also, sometimes, arsenic, selenium, and nitrous acid. From the first it may be purified by dilution with water, in which sulphate of lead is insoluble; but when required entirely pure, it must be distilled, the first portions being rejected.

The presence of sulphuric acid may be detected by any of the soluble salts of barium, such as the chloride of barium, or the nitrate of baryta, the white sulphate of baryta precipitating insoluble in water and acids.

To black woolen clothing this acid communicates a reddish stain, removable by being touched with ammonia.

Besides the compounds just described, we have other definite hydrates of sulphuric acid, thus:

$$(4)\ SO_3 + 2HO.$$

$$(5)\ SO_3 + 3HO.$$

The fourth of these has a specific gravity of 1·78, and crystallizes at 39° Fahrenheit in large and beautiful crystals. The fifth has a specific gravity of 1·632.

HYPOSULPHUROUS ACID, $S_2O_2 = 48{\cdot}266$,

has not yet been isolated; one of its salts, the hyposulphite of soda, is extensively used in the Daguerreotype process for removing the sensitive coating on the plates.

HYPOSULPHURIC ACID, $S_2O_5 = 72{\cdot}355$,

is a sirupy liquid of a very acid taste, and is not applied to any use.

Besides these, we have two other acids of sulphur:

Sulphureted hyposulphuric acid, $S_3O_5 = 88{\cdot}475$, discovered by Langlois.
Bisulphureted hyposulphuric acid, $S_4O_5 = 104{\cdot}595$, discovered by Fordos and Gelis.

Chemists are now very generally agreed that all these

By what substances is it usually rendered impure? How may it be purified? How may it be detected? How may sulphuric acid stains on clothing be removed? What other hydrates of this body are there? What are the uses of hyposulphurous acid? What other sulphur acids are there?

compounds are to be regarded as hydrogen acids—a striking departure from the Lavoisierian doctrines. They have been led to this view by the consideration that no well-marked acid exists in which hydrogen is not found; that all these sulphur acids possess the same neutralizing power, though the quantity of oxygen they contain is so different. They regard them all as being formed by the union of one atom of hydrogen with a series of different compound radicals, as the following table shows:

Sulphurous acid	$H + SO_3$
Sulphuric acid	$H + SO_3 + O.$
Hyposulphurous acid	$H + SO_3 + S.$
Hyposulphuric acid	$H + SO_3 + SO_3.$
Acid of Langlois	$H + SO_3 + SO_3 + S.$
Acid of Fordos and Gelis	$H + SO_3 + SO_3 + S_2.$
Chlorosulphuric acid	$H + SO_3 + Cl.$
Nitrosulphuric acid	$H + SO_3 + NO_2.$
Iodosulphuric acid	$H + SO_3 + I;$

and, extending these views to the constitution of other acids generally, an acid is defined to be "a compound of hydrogen with a simple or compound radical, in which the hydrogen may be replaced by any other metal."

LECTURE L.

SULPHUR AND PHOSPHORUS.—*Sulphureted Hydrogen.—Mode of Preparing it.—Its Odor, Acid Relations, and other Properties.—Extensively used as a Test.—Occurs in Nature.—Relations to the Animal System.—Bisulphureted Hydrogen.*—SELENIUM.—PHOSPHORUS.—*Prepared from Bones.—Shines in the Dark.—Action of Light.—Combustibility.—Compounds with Oxygen.*

SULPHURETED HYDROGEN: $HS = 17{\cdot}12$.

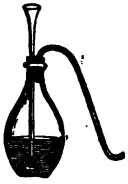
Fig. 228.

THIS gas may be easily prepared by the action of hot hydrochloric acid on the native sulphuret of antimony pulverized, and may be collected over a saturated solution of salt or warm water. The action of the materials being

$$Sb_2S_3 + 3(HCl) \ldots = \ldots Sb_2Cl_3 + 3(HS);$$

that is, one atom of the sesquisulphuret of an-

What is the nature of the views now held in relation to the acids of sulphur, and acids generally? Describe the process for preparing sulphureted hydrogen?

timony and three of hydrochloric acid yield one of the sesquichloride of antimony and three of sulphureted hydrogen.

Fig. 229.

Sulphureted hydrogen is a colorless and transparent gas, having the odor of rotten eggs. It is absorbed by water readily, that liquid taking up two or three times its volume. Its specific gravity is 1·177. It is combustible, and may readily be burned from a jet placed in the flask in which it is being evolved, the products of its combustion being sulphurous acid and water; but if the air in which it is burned be limited in quantity, water alone is produced and sulphur deposited. Its solution in water decomposes gradually by contact with the air, the hydrogen undergoing oxydation, and the sulphur being set free. It has the properties of a weak acid, reddening litmus feebly, and yields with metallic bases water and sulphurets:

$$MO + HS \ldots = \ldots HO + MS.$$

many of these sulphurets being insoluble and highly colored: antimony gives an orange precipitate; arsenic and cadmium, yellow; lead, brown; and manganese, flesh-colored. On this principle, the presence of sulphureted hydrogen may be always detected: the carbonate of lead, for example, is blackened; and hence, white paint exposed in places in which sulphureted hydrogen is being evolved turns dark, and metallic silver tarnishes, and finally becomes black. By a pressure of about seventeen atmospheres the gas may be liquefied.

The action of sulphureted hydrogen on metallic bodies may be illustrated in a very interesting manner by writing on a sheet of paper with a solution of acetate of lead, the letters being invisible until exposed to a stream of this gas, when they turn black. Its action in producing precipitates may be shown by conducting a stream of it through a solution of tartar emetic, arsenious acid, or acetate of lead.

Sulphureted hydrogen is sometimes naturally dissolved in spring water, constituting the mineral waters of various places, as the Virginia Springs. It is also said to be contained in the brackish water of the mouths of large rivers, due, perhaps, to the action of the organic matter they con-

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What are its distinctive properties? What are the results of its combustion? What is the nature of the precipitates it gives with metallic oxides? How may this action be illustrated? Is this gas soluble in water? What is the probable cause of its occurrence at the mouths of large rivers?

tain upon the sulphates existing in the sea. It has been thought by some authors that the existence of this gas in the air of those places is connected with the fevers which there prevail. Sulphureted hydrogen is exceedingly poisonous when respired.

There is another compound of sulphur and hydrogen, the constitution of which is not precisely known, though it is usually described as bisulphureted hydrogen, and its formula is therefore HS_2. In its properties it is said to have several analogies with the deutoxide of hydrogen.

SELENIUM. $Se = 39{\cdot}6$.

This element was discovered by Berzelius in certain varieties of pyrites. It is a rare substance, analogous, in many respects, to sulphur. It burns in the air, forming an oxide which exhales the odor of decaying horseradish.

PHOSPHORUS. $P = 32$.

A remarkable substance, first discovered by Brandt, and now extensively procured from burned bones, in which it occurs as a phosphate of lime. It is found, also, in other animal products, being an essential ingredient in fibrin and albumen, and also in the brain and nervous matter.

Fig. 230.

To procure it, burned bones are reduced to powder, and digested with dilute sulphuric acid; the liquid is strained, mixed with powdered charcoal, and, when dry, introduced into a stone-ware retort, *a*, *Fig.* 230, to the neck of which a bent copper tube, *b*, is attached, the mouth of which dips beneath water. The retort being now exposed in a furnace to a white heat, half the phosphoric acid in the mixture is deoxydized by the charcoal, carbonic oxide gas escaping, and phosphorus distilling over.

Phosphorus is commonly transparent and colorless. When

What other compound of sulphur and hydrogen is there? What is selenium? From what source is phosphorus derived?

exposed to the light it turns of a deep red, and this takes place in a vacuum, or in gases which have no action on the phosphorus. In lustre and general appearance it has a waxy aspect. Exposed to the air it smokes, and in a dark place shines—a property from which its name is derived. During this slow oxydation it exhales an odor much resembling that experienced when an electrical machine is in high activity. At 32° it is brittle, at 113° it melts, at 572° it boils, distilling over unchanged, if oxygen be absent. But in the air it takes fire and burns at about 120°, with evolution of flakes of anhydrous phosphoric acid. Its specific gravity is 1·77.

From the intense affinity which phosphorus has for oxygen, it requires to be kept under the surface of water. It is met with in commerce in the form of small sticks, a form given to it by melting it in glass tubes under warm water, and pushing the resulting cylinders out as soon as they have set. If kept in an opaque bottle it is white, but it slowly turns more or less red on exposure to the daylight.

From the facility with which it takes fire, it is necessary to handle it very carefully, and to avoid keeping it in contact with the warm hand too long. A few particles of dry phosphorus placed between two pieces of brown paper and rubbed with a hard body, take fire and burn furiously as soon as the papers are separated. It is upon this principle that it will readily inflame by the heat of friction, that its useful application in the manufacture of friction matches depends. In chlorine, or the vapor of bromine and iodine, it takes fire spontaneously.

The red variety of phosphorus is commonly regarded as an allotropic modification, or phosphorus in the passive state. Its melting point is much higher than that of the ordinary phosphorus, being higher than 480°. It does not shine in the dark. Its specific gravity is 1·964. It shows no disposition to unite with sulphur, and does not oxydize in the air.

There are several compounds of phosphorus and oxygen, as follows:

What remarkable property does this body possess? Why is phosphorus to be kept under the surface of water? What is the action of light upon it? What useful application is made of its ready combustibility? What are the properties of the red variety of phosphorus? How many compounds of phosphorus and oxygen are there?

$$P_2O \,..\, PO \,..\, PO_3 \,..\, PO_5.$$

These are respectively

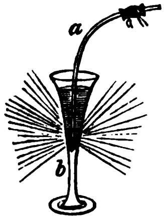
Oxide of phosphorus.	Phosphorous acid.
Hypophosphorous acid.	Phosphoric acid.

LECTURE LI.

COMPOUNDS OF PHOSPHORUS AND OXYGEN. — *Oxide of Phosphorus.—Preparation of.—Hypophosphorous and Phosphorous Acids.—Phosphoric Acid.—Three States of Hydration.—Properties of these three Acids.—Their Salts.—Phosphureted Hydrogen.—Spontaneously Inflammable and Non-inflammable Varieties.*—CHLORINE. —*Preparation of.—Its Relation to Combustion and Respiration.*

OXIDE OF PHOSPHORUS. P_2O.

Fig. 231.



THIS oxide may be formed by causing a stream of oxygen gas, from the tube, *a*, *Fig.* 231, to be directed upon phosphorus under hot water in a glass, *b*. A brilliant combustion under the water is the result, with the production of phosphoric acid and of a red powder, which is the substance in question.

HYPOPHOSPHOROUS ACID, PO,

is very little known; it is formed when phosphorus is boiled in alkaline solutions.

PHOSPHOROUS ACID, PO_3,

is formed during the slow combustion of phosphorus in the air; it may also be produced by acting on the sesquichloride of phosphorus with water. The solution of this acid is sometimes used as a deoxydizing agent.

PHOSPHORIC ACID, PO_5.

Anhydrous phosphoric acid is formed when phosphorus burns in dry air or oxygen gas (*Fig.* 232). It condenses in

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How is oxide of phosphorus made? What is its appearance? How are hypophosphorous and phosphorous acids produced? Under what circumstances is anhydrous phosphoric acid produced?

Fig. 232.

white flakes of a snowy appearance, and possesses an intense affinity for water, in which, if placed, it hisses like a red-hot iron. It can scarcely be said to possess acid properties. Until it has united with water, those properties are very feebly developed.

With water, phosphoric acid unites in three proportions, producing

Monobasic phosphoric acid . . $PO_5 + HO$, or $H + PO_6$.
Bibasic " " . . $PO_5 + 2HO$, or $2H + PO_7$.
Tribasic " " . . $PO_5 + 3HO$, or $3H + PO_8$.

These acids also have the names of metaphosphoric, pyrophosphoric, and common phosphoric acids respectively. Either of them may exist in solution with water.

Metaphosphoric, or the monobasic phosphoric acid, may be obtained by dissolving phosphorus in dilute nitric acid, evaporating, and exposing the residue to a red heat. It may also be obtained by dissolving the anhydrous acid in water, evaporating and igniting it. In both these cases a transparent body, like ice or glass, is produced; hence called glacial phosphoric acid. It contains one atom of water, which can not be removed from it by heat.

Monobasic phosphoric acid is characterized by giving a white granular precipitate with nitrate of silver; it also coagulates albumen, producing white curds. If kept in a solution of water, or boiled with it, it passes into the tribasic state.

Pyrophosphoric, or bibasic phosphoric acid, may be obtained by heating the common phosphoric acid to 417° F. for some time. In solution it neither precipitates silver nor coagulates albumen, but its salts yield, with silver, a flaky white precipitate. Like the former, this turns into the tribasic acid by boiling with water.

Common, or the tribasic phosphoric acid, may be obtained from bone earth by the action of the oil of vitriol, which yields a precipitate of sulphate of lime; or, more easily, by boiling a solution of the anhydrous phosphoric acid. In solution it neither precipitates silver nor coagulates albumen, but its salts yield a Canary-yellow precipitate with the ni-

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How many compounds does it yield with water? How is metaphosphoric acid made? What is glacial phosphoric acid? What are the properties characteristic of monobasic, bibasic, and tribasic phosphoric acids respectively?

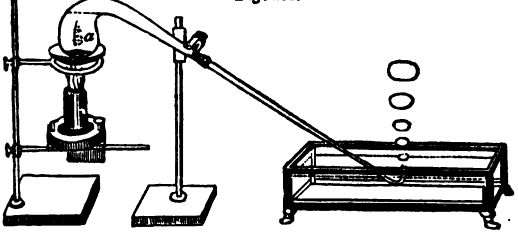
trate of silver. By exposure to a low heat it becomes bibasic, and to a red heat, monobasic.

These hydrogen acids of phosphorus give rise to a very extensive and complex class of salts, according to the extent to which their hydrogen is replaced by metallic bodies. Thus the monobasic phosphoric acid can yield only one series of salts, in which all its hydrogen is replaced by a metal; but the bibasic can yield two different series, according as the metal replaces one or both atoms of base; and the tribasic can yield three different series, according as one or two, or all three of its hydrogen atoms are replaced.

PHOSPHURETED HYDROGEN, $PH_3 = 34{\cdot}4$,

may be made by boiling phosphorus in a strong solution of lime or potash in a retort, *a*, *Fig*. 233, the neck of which dips beneath the surface of water, a few drops of ether being previously put into the retort. As the bubbles of gas break on the water, they take fire, burning with a bright yellow light, and there ascends through the air a ring of gray smoke, which dilates as it rises, and exhibits a curious rotatory movement of its parts. This gas, also, may be made by bringing the phosphuret of calcium in contact with water.

Fig. 233.



Phosphureted hydrogen is a colorless gas, exhaling a peculiar odor, like garlic, and, when burning, produces phosphoric acid and water. It exists under two forms: 1st. Spontaneously inflammable; 2d. Not spontaneously inflammable. It is said that the first may be changed into the second by small quantities of the vapor of ether, oil of turpentine, &c., and the second into the first by the addition of a minute quantity of nitrous acid.

How many series of salts can each class yield? Describe the preparation of phosphureted hydrogen? What are the properties of phosphureted hydrogen? How may its two forms be converted into each other?

CHLORINE. $Cl = 35{\cdot}47$.

Chlorine is found abundantly in nature in union with sodium, forming common salt, a substance which, for the most part, gives to the sea water its salinity, and constitutes the deposits of rock salt. It is, therefore, an abundant substance.

Chlorine is best made by the action of hydrochloric acid on peroxide of manganese:

$$MnO_2 + 2HCl \ldots = \ldots MnCl + 2HO + Cl;$$

that is, one atom of peroxide of manganese and two of hydrochloric acid yield one atom of the chloride of manganese, two of water, and one of chlorine. Half the chlorine is, therefore, given off as chlorine gas, and the other half remains as chloride of manganese.

Chlorine gas being very soluble in cold water, and acting with great energy on mercury, it can neither be collected at the water nor mercurial trough; but, having a specific gravity of 2·470, we are able to collect it by the method of displacement, as shown in *Fig.* 234. It may, however, also be collected over warm water or a saturated solution of common salt.

Fig. 234.

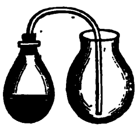
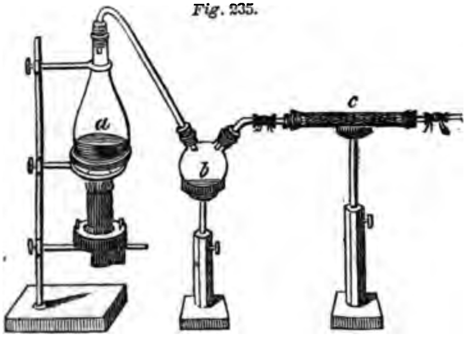


Fig. 235.



When chlorine is required in a state of dryness, it may be obtained by an apparatus like that represented in *Fig.* 235. *a* is the retort containing the hydrochloric acid and manganese. It is connected with a small receiver, *b*, which retains part of the water which the gas may bring over; this,

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In what substances does chlorine chiefly occur? How may it be formed? What are its properties? How is it procured in a state of dryness?

again, is connected with a chloride of calcium tube, *c*, which effects the perfect drying of the gas.

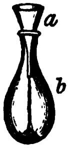
Fig. 236.

Chlorine is a gas of a pale yellowish green color. It may be liquefied by a pressure of four atmospheres. A taper immersed in it burns for a few minutes with a dull red flame, emitting volumes of smoke, due to the fact that the hydrogen of the flame continues to burn or unite with the chlorine, forming hydrochloric acid; but the carbon, having little affinity for chlorine, is set free in an uncombined state, as lampblack. Powdered antimony, or thin brass leaf, plunged in this gas, becomes incandescent, and burns, producing a chloride. A piece of phosphorus immersed in it takes fire at common temperatures, and burns with a pale flame. The smell of chlorine is disagreeable, and its effect, even in a diluted state, suffocating. It irritates the air passages of the lungs, producing hiccough and an unpleasant expectoration.

LECTURE LII.

CHLORINE, CONTINUED.—*Bleaching Properties.—Combustion of Hydrocarbons.—Disinfecting Qualities.—Compounds with Oxygen.—Properties of Hypochlorous, Chlorous, and Chloric Acids.—Quadrochloride of Nitrogen.—Hydrochloric Acid.—Preparation in the Gaseous and Liquid States.*

Fig. 237.



THE most valuable property of chlorine is its power of discharging vegetable colors, on which is founded its application in the arts of bleaching and calico printing. This property may be illustrated in many ways. By pouring a solution of litmus or indigo through a funnel, *a*, *Fig.* 237, into a flask, *b*, containing chlorine gas, the decoloration takes place instantly, or, if the color is not completely discharged, it will be found, in a short time, to disappear. The same takes place when a solution of chlorine in water is used.

What are its relations in the combustion of a taper, and how does it act on certain metals and phosphorus? What is its effects on the animal system? Of the properties of chlorine, which is the most valuable? How may it be illustrated?

Fig. 238.

The peculiarities of chlorine in supporting combustion are remarkable, when compared with those of oxygen gas. A piece of paper, *Fig.* 238, dipped in oil of turpentine, takes fire in a moment at common temperatures when placed in a jar of chlorine, and, as we have seen, phosphorus and several of the metals undergo spontaneous ignition in the same manner. These phenomena depend on the intense affinity which chlorine has for electro-positive bodies, but it is very remarkable that it seems to have little disposition to unite with carbon. As in the burning of a taper, so in this experiment with turpentine, it is the hydrogen which burns, and the carbon is evolved in clouds of smoke.

Chlorine is also used by physicians for the purpose of destroying miasmata, and the effluvia of sick rooms or other places. It is necessary, from its irrespirable qualities, to disengage it slowly and with caution where patients are present. The chlorides of soda and lime are commonly used.

Free chlorine may be detected by its smell, its bleaching action on indigo solution, and giving a white, curdy precipitate with the nitrate of silver. Its solution in water is readily made by introducing a small quantity of water into a bottle full of chlorine, agitating it, and opening the mouth of the bottle from time to time under water ; the gas being gradually absorbed, the bottle becomes full of water, which, of course, contains its own volume of chlorine. This solution decomposes in the sunshine, evolving oxygen gas, the water being decomposed. With oxygen chlorine unites in several proportions, producing

$$ClO \,..\, ClO_4 \,..\, ClO_5 \,..\, ClO_7.$$

They are designated

Hypochlorous acid.
Chlorous acid.
Chloric acid.
Perchloric acid.

HYPOCHLOROUS ACID. $ClO = 43{\cdot}483$.

Hypochlorous acid may be obtained by agitating the red oxide of mercury, suspended in water, with chlorine. If a strong solution of it be placed in an inverted tube, and

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What is the cause of the clouds of smoke deposited when carburets of hydrogen burn in chlorine gas ? For what purpose is chlorine used by physicians ? How may chlorine be detected ? How may a solution of it be made ? What compounds of chlorine and oxygen are known ? How is hypochlorous acid made, and what are its properties ?

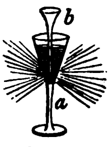
pieces of dry nitrate of lime be added, the gas is disengaged, and rises to the top of the tube. It is of a deeper color than chlorine, bleaches powerfully, and, by a slight elevation of temperature, explodes, evolving two volumes of chlorine and one of oxygen gas.

The bleaching compounds are compounds of chlorides and hypochlorides. They are easily decomposed by acids. Thus, when chloride of lime is to be used for disinfecting purposes, it is merely required to expose it with water to the carbonic acid of the air, or to add a little of it, from time to time, to a vessel containing dilute sulphuric acid.

CHLOROUS ACID, $ClO_4 = 67{\cdot}522$,

may be made by cautiously acting on small quantities of chlorate of potash with sulphuric acid. It is a yellow gas, which explodes furiously from very slight causes, the warmth of the hand being often sufficient to give rise to a violent action. It contains two volumes of chlorine and four of oxygen, condensed into four volumes. It may be conveniently made by operating on a few grains of the chlorate in a test tube. If into a glass, *a*, *Fig.* 239, containing water, a small quantity of chlorate of potash is placed, and upon it a few fragments of phosphorus, and sulphuric acid be poured through a funnel, *b*, so as to act on the chlorate, chlorous acid is set free; it communicates a golden yellow color to the water, and as each bubble passes by the phosphorus it sets it on fire, furnishing a beautiful instance of combustion under water.

Fig. 239.



CHLORIC ACID, $ClO_5 = 75{\cdot}535$,

may be made by decomposing the chlorate of baryta by sulphuric acid, and evaporating the solution. It is a yellow, viscid acid: a piece of paper dipped in it is set on fire. It does not bleach. It forms salts, one of which, the chlorate of potash, is of considerable importance, and is used for the preparation of oxygen. A few grains of the chlorate of potash, ground in a mortar with a pinch of flowers of sulphur, explodes incessantly during the trituration.

PERCHLORIC ACID. $ClO_7 = 91{\cdot}561$.

The perchlorate of potash forms along with the chloride

What are the properties of chloric acid? How may the combustion of phosphorus under water be produced by it? How is chloric acid made?

of potassium when one third of its oxygen is expelled from chlorate of potash; the two salts may be separated from each other by boiling in water, the perchlorate crystallizing on cooling. From this perchloric acid may be obtained by distillation with an equal weight of oil of vitriol, mixed with half as much water. It may be obtained in the form of a white crystalline mass, very deliquescent, and its solution is sometimes used as a test for potash, with which it gives a sparingly soluble salt. The solution fumes in the air, has a specific gravity of 1·65, and does not possess bleaching properties.

CHLORINE AND NITROGEN.

These substances unite, forming an oily liquid, when a warm solution of sal ammoniac is exposed to chlorine gas. The resulting body is regarded as a quadrichloride of nitrogen (NCl_4). By its violent explosions, several eminent chemists have been seriously injured. The mere contact of oily matter produces a detonation.

CHLORINE AND HYDROGEN.

HYDROCHLORIC ACID. $HCl = 36{\cdot}47$.

This acid, called also muriatic acid, is easily prepared by placing in a flask six parts of common salt and ten parts by weight of oil of vitriol, mixed with four of water, the mixture being suffered to cool before it is introduced. On heating the mixture, hydrochloric acid is evolved, which passes along a bent tube into a bottle containing six parts (by weight) of water. The end of the tube dips but a very short distance beneath the surface of this water, so that if the liquid should rise it may be received into a ball blown upon the tube, and the extremity of the tube becoming uncovered, atmospheric air may pass into the interior of the flask. At the close of the process, the liquid in the bottle, which should be constantly surrounded by ice water in a small tank, more than doubles its volume, and is a pure solution of hydrochloric acid. The action is

$$NaCl + 2(HO, SO_3) \ldots = \ldots HCl + (NaO, HO, 2SO_3);$$

that is, one atom of chloride of sodium and two of sulphuric acid yield one atom of hydrochloric acid and one of the bisulphate of soda.

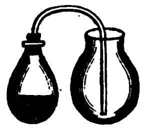
How is perchloric acid prepared, and for what purpose is it used? What are the properties of the chloride of nitrogen? How is hydrochloric acid made?

From the liquid thus produced, or from the commercial muriatic acid, by heating in a flask, pure hydrochloric acid gas may be obtained; it may also be less advantageously procured by the direct action of strong oil of vitriol on common salt, the reaction in this case being

$$NaCl + HO,\ SO_3 \ldots = \ldots HCl + NaO,\ SO_3.$$

Pure hydrochloric acid is a transparent, colorless gas, possessing powerful acid qualities, very absorbable by water, which liquid takes up several hundred times its own volume of the gas; it fumes in moist air, and has a pungent odor. If a dry Florence flask (*Fig.* 240) be filled with it by the process of displacement, and the mouth of it opened under the surface of cold water, the water rushes up into the flask, absorbing the gas with great violence. The specific gravity of hydrochloric acid is 1·284. It contains equal volumes of its constituents, united without condensation.

Fig. 240.



LECTURE LIII.

CHLORINE, CONTINUED.—*Production of Hydrochloric Acid by Light.—Action of Hydrochloric Acid on Metallic Protoxides.—Muriatic Acid Solution.—Detection of Hydrochloric Acid.—Nitro-muriatic Acid.*—IODINE.—*Sources of.—Preparations and Properties.—Tests for Iodine.—Its Action on Starch.—Hydriodic Acid.—Oxygen Compounds of Iodine.*

PURE hydrochloric acid gas is also obtained when a mixture of chlorine and hydrogen, in equal proportions, is exposed to the light. In the dark these gases appear to have no disposition to unite, but if they be placed in a flask covered over with a wire screen, and a beam of the sunlight reflected upon them from a looking-glass, a violent explosion ensues, and hydrochloric acid is formed.

I have found that, in this remarkable experiment, the

How may the gas be procured? What are the properties of hydrochloric acid gas? How may its affinity for water be proved? What is its constitution? What is the action of sunlight on a mixture of chlorine and hydrogen?

action is chiefly due to the chlorine, which, from being in a passive, assumes an active state by exposure to rays of an indigo color. It may be thrown into the same condition in many other ways; for example, by the contact of spongy platina. Moreover, when chlorine by itself has been exposed to the sun, it gains the quality of uniting more easily with hydrogen than chlorine which has been made and kept in the dark.

When hydrochloric acid is brought in contact with metallic oxides, decomposition of both ensues, and metallic chlorides are formed, thus:

$$MO + HCl \ldots = \ldots MCl + HO;$$

or, $$M_2O_3 + 3(HCl) \ldots = \ldots M_2Cl_3 + 3HO;$$

that is, one atom of a metallic protoxide with one atom of hydrochloric acid yields one atom of a protochloride of the metal and one of water. But, in the case of a sesquioxide, one atom of it with three of hydrochloric acid yield one atom of the metallic sesquichloride and three of water.

The constitution of hydrochloric acid, and its action on metallic oxides, may be strikingly illustrated by taking a flask, *b* (*Fig.* 241), filled with it, in a perfectly dry state, and allowing the peroxide of mercury, in fine powder, to fall through it. The bichloride of mercury, corrosive sublimate, instantly forms, and drops of water make their appearance on the sides of the flask.

Fig. 241.

It is under the form of a solution in water, as liquid muriatic acid, or spirit of salt, that hydrochloric acid is chiefly used. The mode of obtaining it has been described in the last Lecture. This liquid, when concentrated, has a specific gravity of 1·21, and contains 42 per cent. of acid. It smokes in the air, and reddens blue litmus powerfully. The commercial acid is usually of a yellow color; it contains chloride of iron, derived from the iron vessels from which it is distilled. It also often contains sulphuric acid, chlorine, sulphurous acid, tin, or arsenic, and is, therefore, best prepared by the process described, which yields it in perfect purity.

Hydrochloric acid may be detected by yielding, when in

To which of these bodies is this action due? What is the action of hydrochloric acid on metallic oxides? What are the products of the action of hydrochloric acid on peroxide of mercury? What are the properties of liquid muriatic acid? What are its impurities?

Fig. 242.

Fig. 243.

a free state with ammonia, dense white clouds of sal ammoniac. If two glasses, one filled with this acid, and the other with ammonia, be brought near each other, a white cloud forms between them. A glass rod, *a* (*Fig.* 243), dipped in ammonia, may be used for the same purpose. With nitrate of silver, hydrochloric acid yields a white chloride of silver, which turns black in the light, being the same precipitate given under the same circumstances by free chlorine. From this latter substance it may be distinguished by litmus water, which is bleached by chlorine, and reddened by hydrochloric acid.

Nitro-muriatic acid, or *aqua regia*, is formed by adding to hydrochloric acid one half or a third of its volume of nitric acid. The nitric acid, furnishing oxygen to the hydrochloric acid, forms water, and chlorine, with nitrous acid, is set free in the solution. Aqua regia is used as a solvent for platina and gold, a result which may be illustrated by placing a sheet of gold leaf in the mixture.

IODINE. $I = 126{\cdot}57$.

Iodine chiefly occurs in the products of the sea, being found in sea-weed, sponge, &c.; and also in certain brine springs, and in some ores of silver and zinc.

It may be obtained by lixiviating the ashes of sea-weeds, and evaporating the solution until no more crystals are deposited. The residual liquor is then acted upon by sulphuric acid, and subsequently heated with peroxide of manganese, in a leaden retort, *a b c* (*Fig.* 244, page 243), the iodine distills over into the receivers, *d*.

It is a solid substance, of a deep blue or black appearance, with a semi-metallic lustre, communicates to the skin a fugitive yellow stain, and exhales an odor like that of sea beaches. It crystallizes in rhomboidal plates, is brittle, and has a specific gravity of 4·948. At 225° it melts, and boils at 347°, exhaling, even at moderate temperatures, a splendid purple vapor, from which its name is derived. The specific gravity of this vapor is 8·707; it is, therefore, one of the heaviest gaseous bodies known.

How may hydrochloric acid be detected? What is the preparation and property of nitro-muriatic acid? From what source is iodine procured? What is the method of its preparation? What is its appearance? What is the color of its vapor? From what circumstance is its name derived?

Fig. 244.

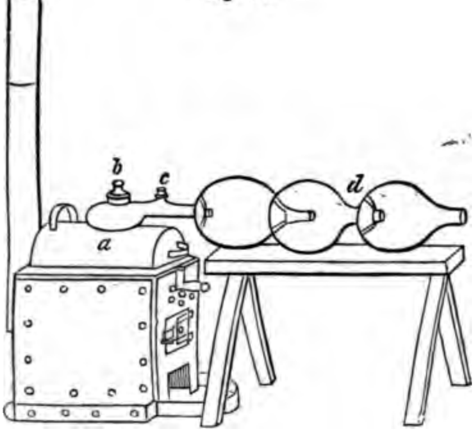
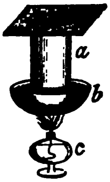


Fig. 245.



Iodine supports combustion much in the same manner as chlorine. A jar, *a* (*Fig.* 245), containing a few grains of it, placed in a small sand bath, *b*, and warmed by a spirit lamp, *c*, may be easily filled with its dense vapor, the atmospheric air floating out before it. In this vapor, if a lighted taper is plunged, it exhibits a retarded combustion; but a piece of phosphorus, introduced on a spoon, takes fire and burns. In the same manner, if a quantity of iodine be placed in a small capsule, and upon it a fragment of dry phosphorus (*Fig.* 246), spontaneous ignition ensues, with the evolution of phosphoric acid, and the vapor of iodine, iodide of phosphorus, remaining in the capsule.

Fig. 246.

In water, iodine is but slightly soluble, that liquid taking up $\frac{1}{7000}$th part of its weight, and assuming a brown color. Alcohol dissolves it freely, forming tincture of iodine. In solutions of the iodides, iodine may be dissolved.

With many substances iodine gives characteristic reactions. The iodide of potassium, with the acetate of lead, yields a golden yellow precipitate; with the bichloride of

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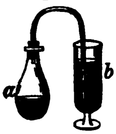
What are its relations as respects combustion? Is it soluble in water and alcohol?

mercury, a fine scarlet-colored biniodide. This substance possesses the singular quality that, if dried and sublimed in a tube, it yields crystals of a brilliant yellow aspect, which become red on being simply touched with a hard body. With a solution of starch, free iodine yields a deep blue color, the solution becoming colorless if heated, but the blue color returning on cooling, provided the temperature has not been carried to the boiling point. If a potato be cut in two, and a little tincture of iodine poured on the surface, innumerable blue specks make their appearance, each corresponding to the position of a granule of starch. Starch and free iodine will, therefore, mutually detect the presence of each other.

HYDRIODIC ACID. $HI = 127{\cdot}57$.

Hydriodic acid gas may be obtained by dissolving in a solution of iodide of potassium as much iodine as it will hold, adding small pieces of phosphorus, and warming the mixture. A colorless transparent gas is evolved, which fumes in the air, and may be collected over mercury. Its specific gravity is 4·384. It has the general relations of hydrochloric acid, and, like it, is very soluble in water.

Fig. 247.



A solution of hydriodic acid in water may be made by passing a stream of sulphureted hydrogen from a flask, *a* (*Fig.* 247), through water, *b*, in which iodine is suspended. The acid forms, and sulphur is deposited:

$$I + HS \ldots = \ldots S + HI.$$

With nitrate of silver this acid yields a pale yellow precipitate, the iodide of silver. This is the substance which forms the basis of the remarkable compound used in the Daguerreotype. In that case it is formed by holding a plate of pure polished silver in the vapor of iodine; the plate tarnishes and turns yellow, and, if set in the sunshine, turns promptly of a deep olive black.

Iodine yields two oxygen acids, iodic (IO_5) and periodic acid (IO_7). With nitrogen, also, it gives NI_4, characterized, like the analogous compound of chlorine, by the facility with which it explodes.

How may it be detected? In what manner is hydriodic acid made? What is the simplest method of obtaining a solution of it? What is the precipitate it yields with nitrate of silver? What are the oxygen compounds of iodine?

LECTURE LIV.

Bromine.—**Fluorine.**—*Bromine.—Sources of.—Properties.—Compounds of.*—**Fluorine.**—*Hydrofluoric Acid.—Its Properties and Action on Glass.*—**Carbon.**—*Allotropic Forms of.—Preparation of some of those Forms.—Diamond.— Oxygen Compounds of Carbon.— Carbonic Oxide.*

BROMINE. $Br = 78{\cdot}39$.

Bromine occurs in sea water, and also, to a more considerable extent, in certain brine springs both in America and Europe. From these it may be obtained by evaporating the water until the salt solution is concentrated, and after the chloride of sodium has crystallized from the liquor, passing through it a current of chlorine gas, the solution turning yellow as the bromine is set free. It is next agitated with sulphuric ether, which carries to the surface all the bromine. This is then acted on by potash, which gives a mixture of bromate of potash and bromide of potassium. On ignition, oxygen is expelled, and the whole converted into the latter salt, from which the bromine may be distilled by the aid of peroxide of manganese and sulphuric acid.

It is a liquid of a deep blood-red appearance, solidifying at—40° F., and boiling at 113° F. Its specific gravity is 2·99. It exhales an orange vapor, and is commonly kept beneath the surface of water. Its smell is very disagreeable, a circumstance from which its name is derived. Like chlorine, it bleaches, and in all its relations possesses a general resemblance to that substance. A lighted taper burns for a short time in its vapor with a greenish flame. Phosphorus burns spontaneously in it.

Bromine yields a hydrogen acid (HBr), hydrobromic acid, and with oxygen, bromic acid (BrO_5). In their general properties these bodies resemble the corresponding compounds of chlorine. The bromide of silver is much more sensitive to light than either the chloride or iodide.

FLUORINE. $F = 18{\cdot}74$,

is found in combination with calcium, as the fluoride of cal-

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From what source is bromine obtained? What are the properties of bromine, and to what bodies has it a close analogy?

cium, or fluor spar. It occurs also in the topaz and other minerals. In the enamel of teeth and in bones it has been detected, especially in fossil bones, which sometimes contain as much as ten per cent. of fluoride of calcium.

The special properties of fluorine are as yet unknown, for it has not been isolated. Various attempts have been made at different times, but without satisfactory results. It possesses an intense affinity for electro-positive bodies, and gives rise to a series of compounds resembling those of chlorine, iodine, &c. It does not unite with oxygen.

HYDROFLUORIC ACID. $HF = 19{\cdot}74$.

This energetic acid may be obtained by decomposing fluoride of calcium by sulphuric acid in a vessel of platina or lead, the vapors being conducted into a metallic receiver kept at a low temperature. The action is

$$CaF + HO,\ SO_3 \ldots = \ldots CaO,\ SO_3 + HF.$$

It is a smoking liquid, which acts powerfully on the skin, boils at a temperature of a little above 60° F., and possesses the remarkable quality of corroding glass.

If a piece of glass be coated over with a thin film of bees' wax, and letters or other marks made through the wax to the glass with a pointed implement, on setting it over a vessel of lead or tin in which, from a mixture of fluor spar and sulphuric acid, hydrofluoric acid is escaping in vapor, the glass is deeply etched on all those parts which have been uncovered, as is seen when the wax is removed. Liquid hydrofluoric acid may be employed for the same purpose, but the letters are not so visible as when the vapor is used.

CARBON. $C = 6{\cdot}04$.

This, which is one of the most interesting and important of the elementary bodies, occurs under many different natural forms. It is an essential ingredient in the structure of all animal and vegetable beings; it is found in various states in the air, the sea, and the crust of the earth.

The striking peculiarity of carbon, which at once arrests our attention, is the different allotropic conditions under which it is presented. This substance may be said to yield in itself a whole group of elementary bodies. Among these

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Are the special properties of fluorine known? How is hydrofluoric acid made? What remarkable quality does it possess? From what sources may carbon be procured? What is its most striking property?

might be enumerated, (1.) Diamond, which crystallizes in octahedrons, is transparent, incombustible, except in oxygen gas, and the hardest body known; hence its use in cutting glass. (2.) Gas-carbon, which, unlike diamond, is a good conductor of electricity, and is opaque. (3.) The various forms of charcoal, anthracite coal, and coke. (4.) Plumbago, which has a metallic lustre, is opaque, and so soft and unctuous that it is used to relieve the friction of machinery. (5.) Lampblack, a powerful absorbent of light and heat, and possessing such strong affinity for oxygen that it can take fire spontaneously in the air.

Other forms of carbon might be cited; these, however, are enough to establish the fact that this single body furnishes varieties which differ more strikingly from each other than many different metallic bodies.

Charcoal is made by the ignition of wood in close vessels, the volatile materials being dissipated and the carbon left. The nature of the process may be illustrated by taking a slip of wood, *b*, *Fig.* 248, and placing its burning extremity in a test tube, *a*. This retards the access of the surrounding air, and, as the combustion proceeds, a cylinder of charcoal is left.

Fig. 248.

Fig. 249.

Lampblack is formed on a similar principle. In the iron pot, *a*, *Fig.* 249, some pitch or tar is made to boil, a small quantity of air being admitted through apertures in the brickwork. Imperfect combustion takes place, the hydrogen alone burning, the carbon being carried as a dense cloud of smoke into the chamber *b c* by the draft. In this there is a hood, or cone, of coarse cloth, *d*, which may be raised or lowered by a pulley. The sides of the chamber are covered with leather, and on these the lampblack collects.

Diamond is the purest form of carbon. Its specific gravity is 3·5: it exhibits a high refractive and dispersive action upon light. Charcoal possesses, in consequence of its porous structure, the quality of absorbing many times its own

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Mention some of its allotropic forms. How are charcoal and lampblack made? What are the properties of diamond?

volume of different gases. Ivory black, which is made by the ignition of bones in close vessels, has the valuable quality of removing organic coloring matters from their solutions: a property which may be shown by filtering a solution of indigo through it. In all its forms, carbon seems to be infusible, but when burned in air or an excess of oxygen, they all give rise to carbonic acid gas. It combines directly with several of the metals, yielding carburets. With oxygen it gives two compounds,

$$CO \ldots CO_2,$$

designated respectively as carbonic oxide and carbonic acid.

CARBONIC OXIDE, $CO = 14{\cdot}053$,

is produced when carbon is burned in a limited supply of oxygen, or when carbonic acid is passed over red-hot iron or over red-hot carbon. In these cases the actions are:

$$CO_2 + C \ldots = \ldots 2(CO).$$
$$CO_2 + Fe \ldots = \ldots CO + FeO.$$

In the first the carbonic acid unites with one atom of carbon, and yields two of carbonic oxide; in the second, it loses one atom of oxygen to the iron and yields one of carbonic oxide. It may also be prepared by heating oxalic acid with oil of vitriol in a flask, *a*, *Fig.* 250, the decomposition giving equal volumes of carbonic acid and carbonic oxide, as is explained under oxalic acid. The acid may be separated by passing the mixture through a bottle, *b*, containing potash water, and the oxide collected over water. But the best process for procuring it is to heat one part of prussiate of potash with ten of oil of vitriol in a retort: the carbonic oxide comes over in a state of purity.

Fig. 250.

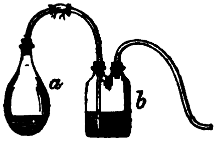
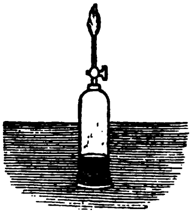


Fig. 251.



As obtained by any of these processes, it is a colorless gas, which may be kept over water, in which it is only sparingly soluble. It is without odor, and is irrespirable. A jet of it burns in the air with

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What are the properties of ivory black? What are the oxygen compounds of carbon? What is the action of carbon and of metallic iron on carbonic acid at a red heat? How is carbonic oxide produced from oxalic acid? From what other substance may it be procured?

a beautiful blue flame, combining with oxygen and yielding carbonic acid. Its specific gravity is 0·9722: it has never been liquefied. It is the combustion of this gas which produces the blue flame often seen in a coal fire. Carbonic oxide is a compound radical, giving origin to a series of bodies.

LECTURE LV.

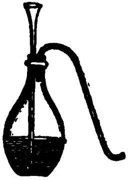
CARBONIC ACID.—*Methods of Preparation by Decomposition and Combustion.—General Properties, and Relation to Combustion and Respiration.—Its Solution in Water.—Exists in the Breath.—Its Liquid and Solid Forms.—Light Carbureted Hydrogen.—Marsh Gas.—Natural and Artificial Production.—Olefiant Gas.—Action with Chlorine.*

CARBONIC ACID. $CO_2 = 23{\cdot}066$.

CARBONIC acid is commonly prepared by the action of dilute hydrochloric acid on chalk, or any carbonate of lime, the action being

$$CaO,\ CO_2 + HCl \ldots = \ldots CaCl,\ HO + CO_2;$$

Fig. 252.



that is one atom of carbonate of lime and one of hydrochloric acid yield one atom of chloride of calcium and one of water, and one atom of carbonic acid gas is set free. The process may be conducted in a flask, as in the figure, the gas being evolved so rapidly that it may be collected over water, though that liquid absorbs it very freely.

Carbonic acid is abundantly formed in many processes. It is the result of the complete combustion of carbonaceous bodies, is evolved during the respiration of animals, and in alcoholic fermentation. It is the *fixed air* of the older chemists.

It is a colorless and transparent gas at common temperatures, with a faint smell and slightly acid taste. It is ir-

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What are the properties of carbonic acid gas? How is this gas made? Under what circumstances is carbonic acid formed during combustion? In what other processes does it appear?

respirable, and acts in a diluted state as a narcotic poison; even air, containing one tenth of its volume of this gas, produces a marked effect. Its specific gravity is 1·527, and it may, therefore, be collected by displacement (*Fig.* 253). For the same reason, it collects in the bottom of wells and pits, and often suffocates workmen who descend into such places. It does not support combustion; a lighted taper lowered into a jar partly filled with it is extinguished the moment it reaches the gas. It may be poured from one vessel to another; and if a jar of it is poured upon the flame of a candle, the light is at once extinguished. Its density and other qualities may be well illustrated when it is formed by the action of fuming nitric acid on carbonate of ammonia, a smoky cloud marking its position and movements.

Fig. 253.

Carbonic acid reddens litmus water, but the blue color is restored on boiling, the acid being driven off by the heat. It is soluble in water, which, under increased pressure, takes up several times its volume of it, constituting the soda water of the shops. Its solubility may be established by agitating it with water in Hope's eudiometer, *Fig.* 254, or by passing it through Nooth's soda-water machine, *Fig.* 255.

Fig. 254.

Fig. 255.

A common test for the presence of carbonic acid in wells is to lower a lighted candle, and if its flame be extinguished, it is inferred that the gas is present; but it does not follow that a man may safely descend into such places though a candle will continue to burn.

If, through a tube, the breath be made to pass into lime-water, a deposit of carbonate of lime renders the water milky; or, if the breath be conducted through litmus water, the color changes to red; the air thus expired from the lungs contains three or four per cent. of carbonic acid.

Under a pessure of thirty-six atmospheres, carbonic acid condenses into a liquid characterized by the extraordinary

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What are the properties of carbonic acid? What are its relations to combustion? What is its specific gravity? What is soda water? How may carbonic acid be detected? How can its existence in the breath be proved?

quality that it is four times more expansible by heat than even atmospheric air. This liquid, when allowed to escape through a jet, evaporates so rapidly, and produces so much cold, that a portion of it instantly solidifies. Solid carbonic acid is a substance not unlike snow; mixed with alcohol or ether, it produces a degree of cold equal to —180° Fahr.

Although carbonic acid has the name of an acid, it possesses the properties indicated by that term in a feeble degree. The gas contains its own volume of oxygen. The common test for its presence is lime-water, which is rendered turbid by it.

CARBON AND HYDROGEN.

These substances unite, producing many compounds, some of which are solid, some liquid, and others gaseous. They are, of course, all combustible bodies, and the description of nearly all of them belongs to organic chemistry.

LIGHT CARBURETED HYDROGEN, $CH_2 = 8{\cdot}04$,

occurs abundantly in coal mines, and forms with their atmospheric air explosive mixtures; it is also found during the putrefaction of vegetable matter under water; on stirring the mud of ponds, bubbles of this gas escape; hence the name marsh gas. It may be obtained artificially by heating acetate of potash with hydrate of baryta.

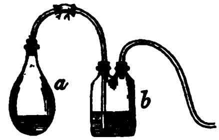
$$(KO) + (C_4H_3O_3) + (BaC, HO) \ldots = \ldots (KO, CO_2) + (BaO, CO_2) + 2CH_2;$$

that is, one atom of acetate of potash with one of hydrate of baryta yield one of carbonate of potash, one of carbonate of baryta, and two of light carbureted hydrogen gas, the acetic acid being decomposed, by the aid of water, into carbonic acid and marsh gas. It is a colorless gas, burns with a yellow flame, producing water and carbonic acid. Its specific gravity is 0·555, forms explosive mixtures with air, and is the fire-damp of coal mines. The choke-damp, which exists in mines after an explosion, is carbonic acid gas, originating from the combustion. This gas is decomposed by chlorine in the light, but not in darkness.

What are the properties of liquid and solid carbonic acid? What is the test for it? How may light carbureted hydrogen be made? Where is it found naturally? Of what does the explosive gas of coal mines consist?

OLEFIANT GAS. $C_4H_4 = 28{\cdot}16$.

Fig. 256.



Olefiant gas may be made by heating one part of alcohol with four of sulphuric acid in a flask, *a*, *Fig*. 256. The vapor of ether which comes over with it may be removed by causing the gas to pass through a small bottle, *b*, containing sulphuric acid, before being collected at the trough. It may also be obtained by an apparatus such as *Fig*. 257, in which *b* is the flask containing alcohol and sulphuric acid, and *a* an interposed globe to receive the ether, oil of wine, and water, which distill over.

Fig. 257.

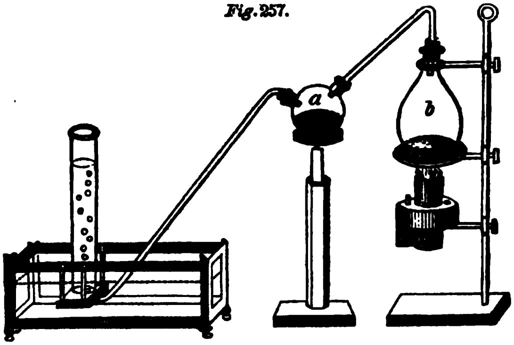
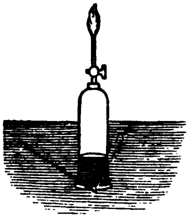


Fig. 258.



Olefiant gas is transparent and colorless; burns with a beautiful flame (*Fig*. 258); forms an explosive mixture with oxygen, giving rise by its combustion to carbonic acid and water. If mixed with an equal volume of chlorine, the gases condense into an oily liquid, from which olefiant gas has received its name. With twice its volume of chlorine, if it be set on fire, hydrochloric acid is formed, and carbon is deposited as a dense black smoke.

Olefiant gas also exists as one of the chief ingredients in the gas employed for illuminating cities.

How is olefiant gas prepared? What are the products of combustion of olefiant gas? What is the action of chlorine on it? From what has it derived its name?

LECTURE LVI.

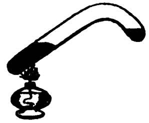
CYANOGEN.—*Modes of Preparation.—Liquefaction.—An Electro-negative Compound Radical.—Bisulphuret of Carbon.*—BORON.—*Boracic Acid.—Terfluoride of Boron.*—SILICON.—*Silicic Acid.—Fluoride of Silicon.—Compounds of Hydrogen and Nitrogen.—Amidogen.—Ammonia.—Ammonium.—Theory of Berzelius.*

CYANOGEN, *Cy*.. OR BICARBURET OF NITROGEN. $C_2N=26.23$.

CARBON unites with nitrogen, forming a bicarburet, when these substances are in the nascent state and in presence of a base. It may be obtained very easily by exposing the cyanide of mercury to heat, or by heating a mixture of six parts of ferrocyanide of potassium and nine of corrosive sublimate.

It is a colorless gas, having a peculiar odor. It burns with a beautiful purple flame, dissolves readily in water, and still more so in alcohol, condenses into a liquid by a pressure of 3·6 atmospheres at 45° Fahrenheit, as may be shown by heating with a lamp cyanide of mercury in a bent tube, as seen in *Fig.* 259; the tube being closed at both ends, liquid cyanogen accumulates at the cool extremity. Though a compound body, it has all the properties and characters of a powerful electro-negative element. A farther description of it and its compounds will be given under organic chemistry.

Fig. 259.



BISULPHURET OF CARBON, $CS_2=38{\cdot}28$,

may be made by passing the vapor of sulphur over charcoal ignited in a tube, and receiving the product in a cold bottle; the apparatus is represented in *Fig.* 260. Into the top of a large iron bottle, two tubes, *b c*, one straight and the other bent, are inserted; the bottle having been filled with charcoal, pieces of brimstone are dropped in through the tube *b* as soon as the bottle is red hot. The sulphur and carbon unite. The product passes along the tubes *c f*, cooled

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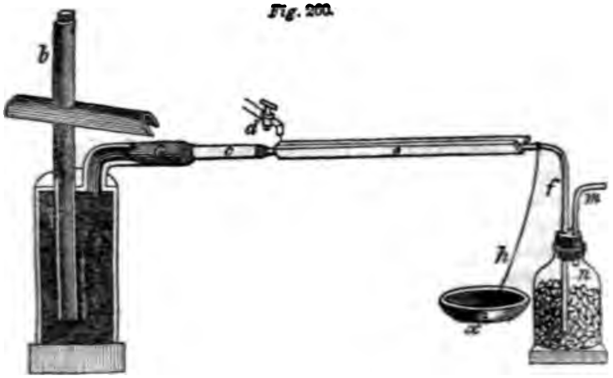
How is cyanogen made? How may it be condensed into a liquid? How is bisulphuret of carbon formed?

[redacted]

Fig. 260.



by a stream of water from the cock, *d*, the water being conducted by a string, *h*, into a basin, *x*. The vapor passes into the bottle, *n*, which is partially filled with ice, and the incondensable gases pass out through *m*. It is a transparent liquid of a very disagreeable odor, has the quality of dissolving sulphur and phosphorus, boils at 108° Fahrenheit, and is therefore very volatile.

BORON, $B = 10{\cdot}9$,

was discovered by Davy as the basis of boracic acid, from which it may be set free by potassium at a red heat. It is an olive-colored solid, which burns when ignited in oxygen gas or atmospheric air, and produces boracic acid.

BORACIC ACID. $BO_3 = 34{\cdot}939$.

Boracic acid exists in the waters of the volcanic springs of Tuscany. It is also brought from India combined with soda, and may be artificially procured by dissolving one part of borax in four of hot water, and adding half a part of sulphuric acid. On cooling, the boracic acid is deposited in small crystalline scales, which may be purified by recrystallization.

Fig. 261.

Boracic acid melts at a red heat into a transparent glass. Its crystals, raised to 212° Fahrenheit, lose half their water. It volatilizes readily when boiled in water, is soluble in

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From what is boron derived? How is boracic acid prepared?

alcohol, the solution burning with a green flame. The experiment may be made in a glass instrument like *Fig.* 261, *a b c.* It is a very feeble acid, and even turns yellow turmeric brown, like an alkali.

TERFLUORIDE OF BORON, $BF_3 = 66{\cdot}94$,

is formed when a mixture of fluor spar, boracic acid, and oil of vitriol is heated in a flask. It is decomposed by water, by which it is rapidly absorbed. In damp air it forms white fumes.

SILICON. $Si = 22{\cdot}18$.

This element may be prepared by igniting the silico-fluoride of potassium with potassium, acting upon the resulting substance with water, which removes the fluoride of potassium, and leaves the silicon as a nut-brown powder.

Fig. 262.

It exhibits two allotropic states. Prepared as first described, it takes fire and burns when heated in atmospheric air; but if previously ignited in close vessels, it shrinks in volume, and, passing into its other state, becomes incombustible in oxygen gas.

SILICIC ACID. $SiO_3 = 46{\cdot}219$.

Silicic acid is one of the most abundant bodies in nature, existing under the innumerable forms of the quartz minerals, sands, and sandstones. Rock crystal and flint are pure silicic acid.

It may be obtained in a more convenient form by fusing white sand with four parts of carbonate of potash, dissolving the resulting silicate in water, and decomposing the solution with hydrochloric acid. The silicic acid separates as a gelatinous hydrate, slightly soluble in water, which, when washed and dried, yields a white powder absolutely insoluble in water. There is reason to believe that the silicon exists in its different allotropic states in these two forms of silicic acid.

Silica is a gritty substance, sufficiently hard to scratch glass. Its specific gravity is 2·66. It combines with the

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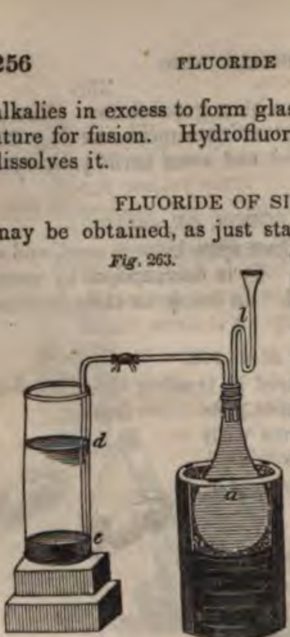
What is the color it communicates to flame? How may silicon be prepared? In what respect does it differ after ignition? What is the constitution of silicic acid, and how may it be prepared? What are its properties?

alkalies in excess to form glass. It requires a high temperature for fusion. Hydrofluoric acid is the only acid which dissolves it.

FLUORIDE OF SILICON, $SiF_3 = 78{\cdot}22$,

may be obtained, as just stated, by dissolving silica in hydrofluoric acid, or by heating a mixture of fluor spar and sand with sulphuric acid. It is colorless; fumes in the air; its specific gravity is 3·66. Transmitted from the flask which generates it, *a*, *Figure* 263, through water, it is decomposed, hydrated silica being deposited. To prevent the tube which delivers the gas being stopped up by the silica, some quicksilver, *e*, may be put in the vessel, *d*, and the tube dipped into it, so that the bubbles of gas may not come in contact with the water until they have reached the surface of the metal; the sulphuric acid may be introduced through the funnel, *l*. In the water, hydrofluosilicic acid forms, which is sometimes used as a test for potash.

Fig. 263.



Nitrogen and Hydrogen yield three compounds:

$$NH_2 \ldots NH_3 \ldots NH_4;$$

they are designated respectively by the names

Amidogen.
Ammonia.
Ammonium.

AMIDOGEN. $NH_2 = 16{\cdot}19$.

Amidogen is a hypothetical compound radical, the existence of which, in several compounds, is inferred. On heating potassium in ammoniacal gas, one third of the hydrogen is set free, and an olive substance remains, the amidide of potassium. This, in contact with water, yields potash and ammonia.

$$K, NH_2 + HO \ldots = \ldots KO + NH_3.$$

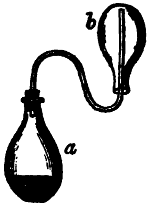
When the fluoride of silicon is passed through water, what are the products? How many compounds of nitrogen and hydrogen are admitted? What is amidogen?

Amidogen is an electro-negative compound radical like cyanogen.

AMMONIA. $NH_3 = 17 \cdot 19$.

This substance, called also *volatile alkali*, from its properties, is an abundant product of the putrefaction of animal matters, and may be obtained by the destructive distillation of horn; hence the term, spirit of hartshorn: it also exists in the air, and is a common product of many chemical reactions.

Fig. 264.



It may be obtained by heating in a flask, *a*, *Fig.* 264, equal quantities of slacked lime and muriate of ammonia, and, as its specific gravity is only 0·590, it may be collected, as in the cut, in a flask or jar, *b*, with the mouth downward, by displacing the heavier air. The action is

$$(NH_3 \times HCl) + (CaO, HO) \ldots = \ldots CaCl + 2HO + NH_3.$$

It is a transparent and colorless gas, of excessive pungency, and having all the qualities of a strong alkali. It turns turmeric paper brown, is absorbed with wonderful rapidity by water, which, at 32° F., takes up 780 times its volume of the gas, a result which may be illustrated by inverting a flask full of it in some cold water, when the water rushes up with sufficient violence to destroy the flask very frequently. Ammonia neutralizes the strongest acids, as may be shown by dropping it into litmus water which has been reddened by sulphuric or nitric acid.

Fig. 265.

It is composed of three volumes of hydrogen with one of nitrogen, condensed into two volumes. It may be recognized by its remarkable odor, and by the formation of white clouds when a rod, *a*, *Fig.* 265, dipped in muriatic acid, is approached to it. It condenses into a liquid at 60° under a pressure of 6·5 atmospheres.

Its solution in water, known as aqua ammoniæ, is prepared by passing the gas evolved from slacked lime and sal ammoniac through Wolfe's bottles, as is represented in

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From what substances may ammonia be procured? What is the specific gravity? What class of bodies does it closely resemble? How may its affinity for water be illustrated? How does it act on reddened litmus water? What is its constitution? How may it be detected? By what process is aqua ammoniæ made?

Fig. 266.

Fig. 266; the water will take it up until its specific gravity is lowered to 0·872; it then contains 32½ per cent of gas. This solution, somewhat diluted, is much used by chemists for neutralizing and precipitating. It also affords the best means of obtaining ammonia, merely requiring to be warmed in a flask, when the gas readily comes off.

AMMONIUM, $Am = NH_4 = 18{\cdot}19$,

is a hypothetical body, and believed to be of a metallic nature; its symbol is, therefore, *Am*. It may be combined with mercury by decomposing a solution of an ammoniacal salt by a Voltaic current, the negative pole being in contact with a globule of that metal, or by putting an amalgam of potassium and mercury in water of ammonia. Under these circumstances, the mercury swells, and eventually becomes of a soft consistency like butter, preserving its metallic aspect completely. All attempts to separate the ammonium from this amalgam have failed. It decomposes into NH_3 and H.

It is now generally agreed by chemists that ammonium is the basis of the salts of ammonia. Thus, sal ammoniac, called also the muriate of ammonia, is $NH_3 + HCl$; but this is evidently the same as $NH_4 + Cl$, that is, the chloride of ammonium. In all cases where ammonia forms neutral salts with the so-called oxygen acids, it requires an atom of water, but this water evidently gives it the constitution, not of $NH_3 + HO$, but $NH_4 + O$; the water,

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What is the nature of ammonium? In what state may it be obtained? How can it be shown that it is the base of the ammonia salts?

therefore, makes it oxide of ammonium, which will unite with sulphuric, or nitric, or any other acid, precisely after the manner of any other metallic oxide. Moreover, the compounds of ammonia with this atom of water are isomorphous with the compounds of the oxide of potassium. From these facts, therefore, we see that when sulphuric acid unites with ammonia, the atom of water which the acid contains gives to the salt the constitution

$$NH_4, O + SO_3, \text{ or } NH_4 + SO_4, \text{ or } Am + SO_4,$$

the latter formula being analogous to $Am + Cl$, the chloride of ammonium or sal ammoniac. This view of the nature of the ammonia compounds is known under the name of the ammonium theory of Berzelius.

Of the compounds of ammonium with other bodies, the protosulphuret, NH_4, S, may be mentioned under the name of hydrosulphuret of ammonia. It is much used as a test. There are also other sulphurets.

What is meant by the ammonium theory of Berzelius?

THE METALS.

LECTURE LVII.

GENERAL PROPERTIES OF THE METALS.—*Definition of a Metal.—Color, Specific Gravity, Hardness, Tenacity, and other Properties.—Relations to Heat.—Compounds with other Bodies.—Division into Groups.—The Oxides and their Reduction.—The Sulphurets and their Reduction.*

OF the elementary bodies, by far the larger portion are metallic. By a metal we mean a body which possesses that peculiar manner of reflecting light which is known under the designation of metallic lustre. It is also a good conductor of electricity and heat. Of these there are at least forty-two, and probably forty-five, three having been recently discovered.

Most of the metals are of a white color, but they differ from each other by slight shades, some having a faint blue and others a pinkish tint. There are three which are strikingly colored: gold, which is yellow, and copper and titanium, which are red. In specific gravity they differ exceedingly; potassium is so light as to float upon water, and iridium is twenty-one times as heavy as that liquid.

Many of the metals are malleable, that is, can be extended into thin sheets under the blow of a hammer; others are so brittle that they may be reduced to powder in a mortar; some of them are ductile, and may be drawn into fine wires, the order for malleability not being the same as that for ductility. Thus, iron may be drawn into fine wire, but can not be beaten out into such thin sheets as many other metals. Of all metals gold is the most malleable, and platina has been drawn into the finest wires.

In hardness the metals differ much. Potassium is so soft

What is the definition of a metal? How many metals are there? What is their color commonly? Which three are the colored metals? Of the metals, which is the lightest, the heaviest, the most malleable, the softest the hardest, the most fusible, and the most volatile?

that it may be moulded by the fingers, but iridium is among the hardest bodies known. In tenacity or strength the same differences are seen: of all metals iron is the most tenacious. The same metal differs very much in this respect at different temperatures.

In their relations to heat, well-marked distinctions also may be traced. Mercury at all ordinary temperatures is in a melted condition; but platina can only be fused before the oxyhydrogen blow-pipe. As respects volatility, mercury, cadmium, potassium, sodium, zinc, arsenic, and tellurium may be distilled or sublimed at a red-heat.

The metals unite with electro-negative bodies and with each other. In decomposition by the Voltaic battery, they pass to the negative pole, and are therefore described as electro-positive bodies. Their compounds with oxygen, chlorine, &c., pass under the names of oxides, chlorides, &c.; their compounds with each other under the name of alloys, or, if mercury be present, of amalgams. They also unite with sulphur, phosphorus, and carbon.

Chemical writers usually divide the metals into groups founded upon their relations with oxygen gas. The following simple division is the one I adopt: 1st. Metals which decompose water at common temperatures; 2d. Metals which can not decompose water at common temperatures, but do it at a red heat; 3d. Metals which can not decompose water at all.

1st Group.

Potassium.
Sodium.
Lithium.
Barium.
Strontium.
Calcium.
Magnesium.

2d Group.

Aluminum.
Glucinum.
Thorium.
Yttrium.
Zirconium.
Lanthanum.
Cerium.
Manganese.
Iron.
Nickel.
Cobalt.
Zinc.
Cadmium.
Tin.

3d Group.

Chromium.
Vanadium.
Tungsten.
Molybdenum.
Osmium.
Columbium.
Titanium.
Arsenic.
Antimony.
Tellurium.
Uranium.
Copper.
Lead.
Bismuth.
Silver.
Mercury.
Gold.
Palladium.
Platinum
Rhodium.
Iridium.

The older chemists divided the metals into four classes: 1st. Alkaline, such as potassium. 2d. Earthy, such as magnesium. 3d. Imperfect, as zinc. 4th. Noble, as gold.

With what other substances do they unite? Into what groups may they be divided? What is the division formerly in use?

THE METALLIC OXIDES.

Metallic substances unite with oxygen with different degrees of intensity, and in very different proportions, many of them giving rise to a complete series of oxides, and producing, 1st. Basic oxides. 2d. Neutral or indifferent oxides. 3d. Metallic acids.

1st. The basic oxides are commonly protoxides or sesquioxides, which form neutral salts with hydrogen acids, with the production of water. To form such salts, for every atom of oxygen in the base there is required one atom of acid. A basic protoxide, therefore, requires one atom of acid, a sesquioxide three, and a deutoxide two, to form a neutral salt.

2d. The neutral, or indifferent, oxides contain more oxygen than the base, and, when heated with acids, give off that oxygen, a basic oxide resulting.

3d. The metallic acids always contain more oxygen; they may be sesquioxides, deutoxides, teroxides, or quadroxides, and are commonly formed by deflagrating the metal with nitrate of potash.

REDUCTION OF THE METALLIC OXIDES.

Some of the oxides, such as those of mercury, silver, and gold, may be reduced by heat alone; but the greater number require the conjoint action of carbon, which, at a high temperature, decomposes them with evolution of carbonic oxide. Among powerful reducing agents may be mentioned the formiates and the cyanide of potassium, the former acting through the affinity of carbonic oxide for oxygen, and the latter through the affinity of carbon and potassium conjointly. The deoxydation of metals may also be accomplished by reducing agents, such as phosphorous and sulphurous acids, or by the action of other metals; iron, for instance, will precipitate metallic copper from its solutions.

Fig. 267.

The Voltaic current affords a powerful means of effecting the reduction of metals in philosophical investigations; by its aid the alkaline metals were originally obtained. The electrotype, already described, is an example of its action; even solutions of metallic salts are readily decomposed by it. Thus, if a glass jar, T,

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What substances do metals yield with oxygen? How are metallic acids commonly made? By what processes may metallic oxides be reduced?

Fig. 267, be divided into halves, and a paper diaphragm be introduced between them, the halves being tightly pressed together by the ring B B, if the jar be filled with any metallic solution, such as the sulphate of soda, and the positive and negative wires of the battery dipped in the opposite compartments, after a time the metallic oxide will be found in one of them and the acid in the other, a total decomposition having taken place.

THE METALLIC SULPHURETS.

Many of these, such as the sulphurets of iron, lead, and copper, are found abundantly in nature; or they may be made artificially by heating the metal with sulphur, or by deoxydizing metallic sulphates by charcoal or hydrogen gas, which converts them into sulphurets; or by the action of sulphureted hydrogen on their oxides, which yields a metallic sulphuret and water. From their solutions under these circumstances, iron, manganese, zinc, cobalt, and nickel can not be precipitated, though they may by hydrosulphuret of ammonia.

The sulphurets of a metal are usually equal in number and similar in constitution to its oxides; and as oxygen compounds unite with each other to produce oxygen salts. the sulphurets, in like manner, also unite with each other to produce sulphur salts.

REDUCTION OF THE SULPHURETS.

The metallic sulphurets may often be reduced by melting them with another metal having a more powerful affinity for sulphur; thus, iron filings will decompose sulphuret of antimony, sulphuret of iron forming, and antimony being set free. On the large scale, however, a different process is resorted to; the sulphuret, by roasting, is converted into a sulphate, much of the sulphur being expelled during the process as sulphurous or sulphuric acid. The resulting sulphate is then acted upon by lime and carbon at a high temperature; the lime decomposes the sulphate, setting free the metallic oxide, which is at once reduced by the carbon, the sulphate of lime turning simultaneously into the sulphuret of calcium, which floats on the surface of the metal as a slag

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By what processes may metallic sulphurets be obtained? What metals can not be precipitated by sulphureted hydrogen? What relation exists between the sulphurets and oxides? How are the sulphurets reduced? What is the process on a large scale?

The metals also unite with chlorine, iodine, bromine, carbon, phosphorus, &c., and some with hydrogen and nitrogen. These compounds will be described in their proper places.

LECTURE LVIII.

Potassium.—*Discovery of, and Properties.—Relations to Oxygen and Water.—Its Oxides.—Caustic Potash.—Tests for Potash.—Haloid Compounds of Potassium.—Salts of the Protoxide, the Carbonate, Nitrate, Chlorate, &c.*

POTASSIUM. $K = 39 \cdot 15$.

Potassium was first obtained by Sir H. Davy, who decomposed its hydrated oxide (potash) by a Voltaic current. From the positive pole oxygen gas escaped in bubbles, and metallic potassium in globules appeared at the negative.

It was subsequently discovered that the same substance could be decomposed by iron, and also by carbon at a high temperature; and the latter of these substances is now exclusively resorted to for the preparation of potassium. The carbonate of potash is ignited with charcoal in an iron bottle, and the potassium received into a vessel containing naphtha. The productiveness of the operation is greatly interfered with by the circumstance that the carbonic oxide which is evolved, as it cools below a red heat, unites with much of the potassium, producing a gray substance, which chokes the tubes and diminishes the yield of the metal.

Potassium is a bluish white metal, which, at 32° F., is brittle, melts at 150° F., and boils at a red heat, yielding a green vapor. Its specific gravity is ·865; it is, therefore, much lighter than water, on the surface of which it floats. At 70° F. it may be moulded by the fingers, being soft and pasty.

Fig. 268.

It possesses an intense affinity for oxygen, and hence requires to be preserved in bottles containing naphtha. A piece of it thrown

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From what was potassium first obtained? What process is now in use for its preparation? What circumstance interferes with the productiveness of this process? What are the properties of potassium?

upon water takes fire, and burns with a beautiful pink flame. In the air it speedily tarnishes, and, even when brought in contact with ice, it decomposes it with the evolution of flame. In these cases the combustion arises from the hydrogen uniting with the oxygen of the air and reproducing water; the potassium simultaneously burns.

POTASSIUM AND OXYGEN.

There are two oxides of potassium, a protoxide and a peroxide,

$$KO \ldots KO_3.$$

The affinity of potassium for oxygen is so great that it takes that substance from almost all other bodies, and hence is used as a powerful deoxydizing agent.

Protoxide of Potassium. $KO = 47 \cdot 163$.

This substance can only be formed by the action of potassium on dry air or oxygen. It possesses a great affinity for water, and is converted by it into the hydrated oxide of potassium, commonly called caustic potash.

Hydrated Oxide of Potassium. $KO, HO = 56 \cdot 176$.

This substance is best procured by boiling two parts of pure carbonate of potash with twenty of water, and having previously slacked one part of quicklime with hot water, the cream which it forms is to be added by degrees, and the whole boiled. The process should be conducted in an iron vessel to which a lid can be adapted, so as to exclude the air during cooling; the resulting carbonate of lime settles perfectly, and the hydrate may be obtained by evaporating the solution rapidly in a silver vessel, pouring out the melted residue on a silver plate, or casting it into the form of small cylinders.

The decomposition which takes place in the foregoing process is simple,

$$KO, CO_2, + CaO, HO \ldots = \ldots CaO, CO_2 + KO, HO;$$

that is, the lime takes carbonic acid from the carbonate of potash, and the oxide of potassium unites with water. The solution may be known to be free from carbonic acid by not effervescing when mixed with stronger acids.

The hydrate of potash is a white solid, having a power-

How many oxides does it form? How is the hydrated oxide, or caustic potash, obtained? What is the nature of the decomposition? Of what properties is the hydrate of potash possessed, and what are its uses?

ful affinity for water, and abstracting it rapidly from the air. Taken between the fingers, it communicates to the skin a soft feel, and, if a concentrated solution be used, soon effects a disorganization; hence it is used by surgeons in the form of small sticks as an escharotic. It possesses pre-eminently the alkaline qualities, and, indeed, may be taken as the type of that class of bodies, neutralizes the most powerful acids perfectly, and communicates to turmeric paper, or turmeric solution, a brown tint. It turns the infusion of red cabbage green, and, possessing an intense affinity for carbonic acid, is used in organic analysis to absorb that gas.

Potash in combination occurs in all fertile soils, and is essential to the growth of land plants, from the ashes of which its carbonate is abundantly procured. This may be shown by filtering water through the ashes of wood, when the clear liquid will be found to answer to all the tests indicating the presence of potash. It occurs also abundantly in feldspar, and hence is found in clays. The want of fertility in soils appears occasionally to be due to the absence of this body.

The bichloride of platinum gives, with a solution of potash, a yellow precipitate of the chloride of platinum and potassium. When the amount of potash is small, it is well to add alcohol at first, in which the double chloride is insoluble. Ammonia yields a similar precipitate; but this may be avoided by exposing the substance, in the first instance, to a red heat before testing. Perchloric acid, with alcohol, yields a white precipitate. Tartaric acid, if added in excess, and the mixture stirred with a glass rod, bearing gently on the sides of the vessel, gives white streaks of the bitartrate of potash wherever the rod has passed over the glass.

Of other compounds of potassium, the following may be mentioned:

Peroxide of potassium, KO_3.
Chloride of potassium, KCl.
Iodide of potassium, KI.
Bromide of potassium, KBr.
Protosulphuret of potassium, KS.
Pentasulphuret of potassium, KS_5.

It also combines with hydrogen in two proportions, producing a solid and a gas, the latter of which takes fire spontaneously in the air.

How may the existence of potash in the ashes of plants be proved? What are the tests for the presence of the substance? Name some of its other compounds.

Of these compounds, the most important are the peroxide of potassium, which is formed by passing oxygen over red-hot potash; it is decomposed by water, evolving oxygen and producing potash; the chloride of potassium, which is analogous to common salt; the iodide, much of which is consumed in medicine, under the name of hydriodate of potash. It may be prepared by dissolving iodine in a solution of potash till the liquid begins to appear brown, then evaporating to dryness, and igniting the residue: oxygen is evolved, and iodide of potassium remains; it may be then dissolved in water, and crystallized. It is white, crystallizes in cubes, and is very soluble in water and hot alcohol. Its solution will dissolve large quantities of iodine. The pentasulphuret is the chief ingredient of liver of sulphur, which is formed by fusing sulphur with carbonate of potash at a low temperature.

SALTS OF THE PROTOXIDE OF POTASSIUM.

Carbonate of Potash is obtained by lixiviating the ashes of plants. In an impure state it forms the potashes and pearlashes of commerce. It may be obtained pure by igniting the bitartrate with half its weight of the nitrate of potash. It has an alkaline taste, its solution feels greasy to the fingers, it is very soluble in water, and deliquescent.

Bicarbonate of Potash, formed by transmitting a stream of carbonic acid through a solution of the former salt. It crystallizes in eight-sided prisms with dihedral summits.

Sulphate of Potash, formed by neutralizing the following salt. Crystallizes in anhydrous, oblique, four-sided prisms, soluble in about ten times its weight of water.

Sulphate of Potash and Water, sometimes designated as the bisulphate of potash; it is the residue of the production of nitric acid. It is soluble in water, and has an acid reaction. It crystallizes in rhombohedrons.

Nitrate of Potash is extracted on the large scale from certain soils in which organic matter is decaying in contact with potash. It crystallizes in six-sided prisms, fuses at a heat beneath redness, with evolution of oxygen gas. It is soluble in about three times its weight of water, at common temperatures. This salt enters as an essential ingredient in gunpowder, which is composed of about one atom of nitrate

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What are the properties of the iodide? From what is the carbonate obtained? What is the origin and use of the nitrate?

of potash, one of sulphur, and three of carbon. The sulphur of this mixture accelerates the combustion, while the oxygen of the nitre forms carbonic acid with the charcoal. The products, therefore, of the perfect combustion of gunpowder are carbonic acid, nitrogen, and the sulphuret of potassium. It commonly happens, however, that sulphate of potash is formed. The proportions of the ingredients of gunpowder are varied for different uses. The powder used for mining, for example, contains more sulphur than that used for fire-arms.

Chlorate of Potash.—When a stream of chlorine is passed into a solution of potash, the chloride of potassium and the chlorate of potash result; the latter is deposited in flat, scaly crystals.

The chlorate of potash contains no water; it dissolves in about fifteen times its weight of that fluid; melts at a red heat, with evolution of pure oxygen; deflagrates with combustible bodies, sometimes with much violence.

LECTURE LIX.

SODIUM. —*Preparation of.—Relation to Oxygen and Water.—Color communicated to Flame.—Its Oxides.—The Hydrated Oxide.—Tests for Sodium.—Haloid Compounds.—Common Salt.—Salts of the Protoxides, Carbonates, Sulphates, Nitrates, &c.*—LITHIUM.—BARIUM.—*Its Oxides.—Haloid Compounds.—Salts of the Protoxide.*

SODIUM. $Na = 23{\cdot}3$.

SODIUM may be obtained by the same process as potassium, but is best procured by igniting the calcined acetate of soda with powdered charcoal in an iron bottle; and, as the sodium does not act upon carbonic oxide, the operation is much more productive than in the case of the other metal. Like potassium, it is to be kept in bottles under the surface of naphtha.

In color, sodium resembles silver; its specific gravity is 0·9348; it therefore floats upon water. It melts at 194°

How is the chlorate of potash made? How is sodium obtained, and what are its uses? What are its properties compared with potassium?

F., and is more volatile than potassium. Thrown upon water, it decomposes it with a hissing sound, and with the evolution of hydrogen, but no flame appears. If, however, the water is hot, then a beautiful yellow flame, characteristic of sodium and its compounds, is the result.

SODIUM AND OXYGEN.

With oxygen sodium forms three compounds: the suboxide, protoxide, and peroxide.

Protoxide of Sodium. $NaO = 31{\cdot}313$.

This, like the corresponding potassium compound, is produced by oxydizing sodium in dry air. It is a white powder, which attracts moisture from the air and forms the hydrated oxide of sodium, commonly called caustic soda.

Hydrated Oxide of Sodium, $NaO + HO = 40{\cdot}323$, or caustic soda, may be made by the same process as that given for caustic potash, by using carbonate of soda, and, when the resulting carbonate of lime has settled, evaporating the liquid. The best proportions are one part of quicklime to five of carbonate of soda in crystals.

Caustic soda resembles caustic potash in most of its properties. It is deliquescent, has a strong affinity for carbonic acid, and acts upon animal tissues as an escharotic. Its salts are generally more soluble than the potash salts, and on this are founded the methods recommended for distinguishing the latter compounds from it. Moreover, the soda compounds communicate to the flame of alcohol, or to the blow-pipe, a yellow color: the same tint which is characteristically seen when sodium is placed in hot water.

Chloride of Sodium. $NaCl = 58{\cdot}77$.

The chloride of sodium, common salt, is obtained abundantly from the waters of the sea, to which it gives their salinity. It is also found as rock salt, deposited extensively in certain geological formations.

Common salt is the general type of that extensive class of compounds which have derived the name of salt bodies from it. It crystallizes in cubes, and, when in mass, is often perfectly transparent, and permits the passage of heat of

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What compounds with oxygen does it give? How is caustic soda obtained? What are its properties and uses? What color do the sodium compounds give to flame? What is the constitution of common salt? From what sources is it derived? What are its properties?

every temperature through it freely. It melts into a liquid at a red heat, crystallizes in cubes, and is not more soluble in hot than cold water. It is extensively used in the preparation of hydrochloric acid and chlorine; immense quantities, also, are annually consumed in the preparation of carbonate of soda, which is made by first acting on the common salt with oil of vitriol, so as to turn it into sulphate of soda, and igniting this with charcoal and carbonate of lime: an impure carbonate of soda is the result, known under the name of black ash, or British barilla. Common salt is extensively used for the curing of meat. It is also an essential article of food, being decomposed in the animal system, and furnishing hydrochloric acid to the gastric juice and soda to the bile.

The compounds of sodium with bromine, iodine, sulphur, &c., are not of interest.

SALTS OF THE PROTOXIDE OF SODIUM.

Carbonate of Soda is sometimes obtained by lixiviating the ashes of sea-weeds. Large quantities are also procured from the decomposition of sulphate of soda by saw-dust and lime at a high temperature, the carbonaceous matter decomposing the sulphuric acid and generating carbonic acid, which unites with the soda, while the liberated sulphur is partly dissipated and partly unites with the calcium. From the resulting mass carbonate of soda is obtained by lixiviation. The crystals, as found in commerce, contain generally ten ounces of water; there are two other varieties, the one containing eight atoms, and the other one atom of water. Large quantities of the carbonate of soda are also sold in an uncrystallized state, under the name of salts of soda. The figure of the crystals of this salt is a rhombic octahedron. They effloresce on exposure to the air. They are soluble in five times their weight of cold and in less than their own weight of boiling water.

Bicarbonate of Soda, or the double carbonate of soda and water, is formed by transmitting a stream of carbonic acid through a solution of the carbonate, and is in the form of a white powder. It is less soluble in water than the former. There is a sesquicarbonate, which passes in commerce under the name of trona.

How is barilla obtained from common salt? Why is it essential as an article of food? From what source is the carbonate of soda obtained? Describe the preparation of it from the sulphate.

Sulphate of Soda is the Glauber's salt of the shops; occurs as a natural product, and also as the result of the preparation of hydrochloric acid. It is in prismatic crystals of a bitter taste, efflorescing in the air, and becoming anhydrous. Water dissolves more than half its weight of this salt at 91½° F., but above that degree it is less soluble. When a solution of three parts of this salt in two parts of water is corked up in a flask while boiling, it may be cooled without crystallization taking place; but if the cork is withdrawn, crystallization commences at once, or if it does not, the introduction of any solid matter produces it, and the temperature of the solution at once rises.

Nitrate of Soda is found abundantly in different parts of America in the soil; it crystallizes in rhomboids, dissolves in twice its weight of cold water, and, from its deliquescence, can not be used in the manufacture of gunpowder.

Phosphate of Soda (tribasic) is formed by neutralizing phosphoric acid with carbonate of soda; two of the hydrogen atoms are replaced; it crystallizes in oblique rhombic prisms, dissolves in three times its weight of cold water, is of an alkaline taste, and gives a lemon-yellow precipitate with nitrate of silver. By the addition of soda to it a subphosphate is formed, in which all three of the hydrogen atoms of the acid are replaced; but by the addition of phosphoric acid to the ordinary phosphate, till it ceases to give any precipitate with chloride of barium, the biphosphate of soda results, a salt very soluble in water. Its crystals are rhombic prisms. In it only one of the hydrogen atoms is replaced.

Microcosmic Salt, or the phosphate of soda, ammonia, and water, is made by dissolving seven parts of phosphate of soda in two parts of water, and adding one part of sal ammoniac. At a low heat it parts with its water of crystallization, and the temperature rising, it loses its ammonia and saline water, becoming monobasic phosphate of soda. It is much used in blow-pipe experiments.

Pyrophosphate of Soda (bibasic) is procured by heating the phosphate. It gives a white precipitate with nitrate of silver.

What is the commercial name of the sulphate of soda? What peculiarity is there in the crystallization of its solution? Why can not the nitrate be used for gunpowder? What is the difference between the phosphate, the pyrophosphate, and the metaphosphate of soda? What is microcosmic salt?

Metaphosphate of Soda (monobasic) is formed by heating microcosmic salt to redness. It is soluble in water, melts at a red heat, and gives, with dilute solutions of the earthy and metallic salts, viscid precipitates.

Biborate of Soda, the borax of the shops. It is imported in a crude state from the East Indies, and manufactured from the natural boracic acid of Italy by the addition of carbonate of soda. It crystallizes in octahedrons, or in oblique prisms, the former containing five, the latter ten atoms of water, all of which is lost by exposure to a red heat, the salt then fusing into a glass. It is of great use in blowpipe experiments.

LITHIUM. $L = 6{\cdot}42$.

This rare metal occurs in certain minerals, such as spodumene, lepidolite, &c. It is a white metal, communicating to flame a red color. It yields a protoxide, the carbonate of which is of sparing solubility in water, thus forming the link of connection between the potash and soda carbonates, which are very soluble, and the carbonates of the alkaline earths, as baryta and strontia, which are insoluble.

This brings us to the metals of the alkaline earths, which form a division of our first group; the first of these is

BARIUM. $Ba = 68{\cdot}7$.

The existence of barium was first proved by Davy, who isolated it by electrifying mercury in contact with the hydrate of baryta; an amalgam formed, from which the mercury was subsequently distilled, leaving the barium as a metal of a gray color like cast iron, heavier than sulphuric acid, in which it sinks, obtaining oxygen rapidly from the air, and giving rise to the production of the protoxide of barium, baryta.

Protoxide of Barium; $BaO = 76{\cdot}713$,

may be obtained by igniting the nitrate of baryta, the decomposition being

$$BaO,\ NO_5 \ldots = \ldots BaO + NO_4 + O\,;$$

that is, one atom of nitrate of barytes yields one of protox-

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From what source is borax derived, and what are its uses? In what minerals does lithium occur? What is the relation of its carbonate to those of the preceding and subsequent metals? How was barium first obtained? What is the process for obtaining the protoxide, and also its hydrate?

ide of barium, and one of nitrous acid and one of oxygen gas are expelled.

This protoxide is a white colored body, possessing a strong affinity for water, with which it exhibits the phenomenon of slacking, as is the case to a less extent with lime, heat being evolved. It has an acid taste, is soluble in water, and absorbs carbonic acid from the air. Its specific gravity is about 4·000. Its soluble salts are poisonous.

Hydrate of Baryta, $BaO, HO = 85{\cdot}726$,

is formed by slacking the protoxide, and is a white powder, very soluble in hot, but less so in cold water, yielding, therefore, crystals when a hot solution cools: these contain nine atoms of water of crystallization. The cold solution is used as a test for carbonic and sulphuric acids, with which it forms insoluble white precipitates.

This solution is most easily obtained by calcining the native sulphate with pulverized charcoal, which converts it into the sulphuret of barium. To a boiling solution of this body oxide of copper is added till the liquid ceases to blacken a solution of acetate of lead. On being filtered, the solution of hydrate of barytes is obtained.

Peroxide of Barium, $BaO_2 = 84{\cdot}7$,

is made by igniting chlorate of potash with barytes, or by passing oxygen over barytes in a red-hot tube. It is used in the preparation of peroxide of hydrogen.

Of the other compounds of barium, the chloride is much used as a test for sulphuric acid; it may be made by decomposing carbonate of baryta by hydrochloric acid. The sulphuret of barium is made by igniting the sulphate of baryta, heavy spar, with charcoal, which deoxydizes both the sulphuric acid and the baryta. It dissolves in hot water, and from this solution a solution of caustic baryta may be obtained by boiling with the oxides of lead or copper, and separating the sulphurets of those metals by filtration. By acting upon it with hydrochloric or nitric acid, the chloride or nitrate of baryta may be prepared.

SALTS OF THE PROTOXIDE OF BARIUM.

Carbonate of Baryta is found native, as the mineral

What acids is a solution of baryta used to detect? How is the peroxide made? What is its use? For what purpose is the chloride of barium employed?

Witherite, and may be prepared by precipitating a soluble salt of baryta with an alkaline carbonate. It is soluble in 4300 times its weight of cold water, and 2300 of boiling water.

Sulphate of Baryta, found native abundantly as *heavy spar*, and from it most of the compounds of barium are prepared. It is called heavy spar, its density being 4·47. It crystallizes generally in tabular plates, and is wholly insoluble in water.

LECTURE LX.

STRONTIUM.—*Uses in Pyrotechny.—Salts of Protoxide.*—CALCIUM.—*Protoxide of.—Sources in Nature.—Tests for.—Haloid Compounds, Chloride, Fluoride, Sulphurets, &c.—Salts of the Protoxide, Carbonate, Sulphate, Phosphate, Chloride.* — MAGNESIUM. — *Protoxide.* — *Salts of Protoxide, Carbonate, Sulphate, Double Phosphate.* — ALUMINUM. —*Sesquioxide.* — *Uses in the Arts.* —*Tests.—Salts of the Sesquioxide, Double Sulphate, Alum.—Manufacture of Porcelain and Glass.—Other Metals.*

STRONTIUM. $Sr = 43{\cdot}8$.

THIS metal may be obtained by the same processes which have been used for obtaining barium, with which it has a considerable analogy. Its natural compounds are the sulphate and carbonate, from which its other preparations may be obtained.

Strontium yields a protoxide, which is the basis of a series of salts, differing from baryta salts in not being poisonous. The chloride and nitrate are used in pyrotechny for the purpose of communicating to flame a brilliant crimson color. The red fire of theatres contains the latter salt, and the former, if dissolved in alcohol, communicates to its flame the characteristic test of the strontium compounds.

How may the sulphate of barytes be converted into the sulphuret of barium? What are the properties of the carbonate and sulphate of baryta? In what respect does strontium differ from barium? What is the color it communicates to flame?

SALTS OF THE PROTOXIDE OF STRONTIUM.

Carbonate of Strontia is the *strontianite* of mineralogists.

Sulphate of Strontia is the *celestine* of mineralogists. It is not so heavy as sulphate of baryta, and is said to be soluble in about 4000 times its weight of boiling water.

Nitrate of Strontia forms an ingredient of the red fire used in theatres; it crystallizes in octahedrons, and is soluble in five times its weight of cold water, and half its weight of boiling water.

CALCIUM. $Ca = 20{\cdot}5$.

Calcium has never been obtained in quantities sufficient to permit a full examination of its properties. It oxydizes with rapidity, yielding a protoxide, known also as quicklime or lime.

Lime occurs as a carbonate in the various limestones, marbles, chalks, &c., which form in many countries extensive mountain ranges. Its other salts are very abundant.

From the carbonate, pure or quicklime may be obtained by exposure to a bright red heat. If the limestone contains silica, it may, however, be *overburnt*, a silicate of lime forming, which prevents the product from slacking. It possesses a strong affinity for water, and unites therewith with a great elevation of temperature, as exhibited in the process of slacking. Exposed to a high temperature, it phosphoresces splendidly. The hydrate which forms when lime is slacked is white; it is soluble to a small extent in water; and it is remarkable that cold water dissolves much more than hot. Lime-water is colorless, of a partially caustic taste, neutralizes acids perfectly, restoring to reddened litmus its blue color. It is used as a test for carbonic acid, with which it gives the white carbonate of lime. Milk of lime is nothing but lime-water in which hydrate of lime is mechanically suspended. The hardening of lime mortars depends chiefly on the absorption of carbonic acid. Hydraulic lime possesses the quality of setting under water. It contains oxide of iron, alumina, and silica.

Lime is best detected by oxalate of ammonia, with which

What are the mineralogical names of the carbonate and sulphate of strontia? What is lime? Under what forms does it occur in nature? From the carbonate, how may lime be produced? What is the action of water on it? What are the properties of lime-water? What is milk of lime?

it gives a white precipitate of oxalate of lime, provided the solution be not acid.

Among other compounds of calcium may be mentioned

Chloride of Calcium, $CaCl = 55{\cdot}97$,

formed by dissolving carbonate of lime in hydrochloric acid, evaporating the solution to a sirup, and, on cooling, the chloride crystallizes. It is exceedingly deliquescent. Chloride of calcium, dried without crystallization, is used in organic analysis for collecting water, and, generally, in other chemical operations for drying gases.

Fluoride of Calcium, $CaF = 39{\cdot}24$,

called, also, fluor spar, and frequently found as a mineral associated with lead. Crystallizes in cubes, octahedrons, &c., of various colors. It is found in fossil, and, to a smaller extent, in recent bones. It is used for various ornamental purposes, and is the source from which the compounds of fluorine are derived.

Sulphuret of Calcium, $CaS = 36{\cdot}62$,

obtained by igniting the sulphate of lime with charcoal, and constitutes Canton's phosphorus, commonly made by igniting oyster shells with sulphur; possesses the curious quality of shining in the dark, after a brief exposure to the sun or to the rays of an electric spark.

SALTS OF THE PROTOXIDE OF CALCIUM.

Carbonate of Lime is abundantly found in nature, forming whole ranges of mountains, the limestones, marbles, &c., of mineralogists. It occurs pure in the form of Iceland spar, in rhomboidal crystals, possessed of double refraction. It is dimorphous, assuming the form of six-sided prisms, as in the mineral called Arragonite. It is anhydrous, insoluble in water, but in water charged with carbonic acid it is soluble, and is deposited from such a liquid on boiling, or by the diffusion of carbonic acid into the air. The carbonic acid is expelled from this salt by a red heat, and the action of the more powerful acids. Carbonate of lime may be obtained in union with water, by boiling hydrate of lime with a solution of sugar.

For what purposes is the chloride of calcium used? Under what forms does fluoride of calcium occur? What singular quality does the sulphuret of calcium possess? What are the dimorphous forms of carbonate of lime? Under what circumstances is it soluble in water?

Sulphate of Lime—Gypsum—occurs native, both in crystals, the primary form being a rhombic prism, and also in extensive crystalline masses. It contains two atoms of water; there is a variety, however, passing under the name of anhydrite, which contains no water. On calcining the hydrous sulphate of lime at a low red heat, it becomes plaster of Paris, and has the property of setting into a hard mass when made into a paste with water. The sulphate of lime is soluble in 500 parts of boiling water, and often occurs in the water of springs, to which it communicates hardness.

Phosphate of Lime—Bone-earth Phosphate—is one of the tribasic phosphates; it is precipitated when earth of bones is dissolved in muriatic acid, and the solution neutralized by ammonia.

Chloride of Lime—Bleaching Powder—is made by exposing hydrate of lime to chlorine. It is a white powder, exhaling a faint odor of chlorine, and is used extensively as a bleaching agent.

MAGNESIUM. $Mg = 12\cdot7$.

Magnesium may be procured by igniting a mixture of chloride of magnesium and sodium in a porcelain crucible the chloride of sodium forms, and magnesium is set free The chloride may be dissolved by water.

It is a white, malleable metal, which melts at a red heat, and, with excess of air, oxydizes, forming

Protoxide of Magnesium. $MgO = 20\cdot713$.

This substance, called, also, *calcined magnesia*, or simply *magnesia*, may be made by heating the carbonate to low redness; the carbonic acid is driven off, and the magnesia remains as a white powder, insoluble in water, but neutralizing acids completely, and forming with them a complete series of salts.

Magnesia occurs very abundantly in nature, often associated as a carbonate with carbonate of lime, as in dolomitic limestone. It also occurs in fertile soils, and is essential to the growth of certain plants.

It is well distinguished from all the foregoing alkaline earths by the relation of its sulphate. The sulphates of

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Under what forms does sulphate of lime occur, and for what purpose is it used? In what does the phosphate of lime occur? What is bleaching powder? How is magnesium obtained? What are the properties of it? Under what names does the protoxide pass? What is dolomitic limestone?

baryta, strontia, and lime form a series of salts, the solubility of which, in water, is constantly increasing; to these the corresponding magnesia salt may be added; it is very soluble.

Magnesia is precipitated from its sulphate by the caustic alkalies, and by the carbonates of potash and soda as a carbonate, but not by the carbonate of ammonia in the cold. It may be detected by adding carbonate of ammonia and phosphate of soda in succession, when the phosphate of magnesia and ammonia is precipitated. Heated before the blow-pipe, after having been moistened with nitrate of cobalt, magnesia becomes of a pinkish color.

SALTS OF THE PROTOXIDE OF MAGNESIUM.

Carbonate of Magnesia is found native, and may be prepared by boiling the sulphate with an alkaline carbonate, diffusing the precipitate in water, and passing a stream of carbonic acid through it; by spontaneous evaporation, the carbonate of magnesia is deposited in crystals. The carbonate of magnesia, the *magnesia alba* of the shops, is prepared by precipitating the sulphate of magnesia with the carbonate of potash; it occurs in light white cubical cakes, or in powder, and is not a true carbonate, for it does not contain a full equivalent of carbonic acid. It is said to be a compound of one atom of hydrate of magnesia with three atoms of hydrated carbonate of magnesia. It is very slightly soluble in water.

Sulphate of Magnesia—Epsom Salts of commerce—is produced by the action of dilute sulphuric acid on magnesian limestone. Its crystals are small four-sided prisms, soluble in an equal weight of cold and three fourths their weight of boiling water, the solution having a bitter taste A low heat expels six out of the seven equivalents of the combined water.

Phosphate of Magnesia and Ammonia, one of the varieties of urinary calculus, may be formed artificially when a tribasic phosphate, a salt of ammonia, and a salt of magnesia are mixed together.

Magnesium is the last of the alkaline earthy metals. Its history completes that of our first group of metallic bodies.

How may magnesia be detected? How is its carbonate prepared? Of what is Epsom salt composed? In what form is the phosphate of magnesia and ammonia sometimes found?

At the head of the second group we find aluminum, the first of the earthy metals.

ALUMINUM. $Al = 13{\cdot}7$.

Obtained, by Wholer, by the action of sodium on the chloride of aluminum, being the same process as that given for the preceding metal.

It is a gray powder, which melts beneath a red heat; takes fire when heated in air, producing

Sesquioxide of Aluminum. $Al_2O_3 = 51{\cdot}539$.

This oxide, called, also, alumina and clay, occurs naturally under certain forms, which are highly prized, as the ruby and sapphire. In a more impure condition it yields the various common clays, which also contain silica or metallic oxides, or other extraneous bodies.

Alumina may be prepared from the sulphate of alumina and potassa, common alum, by precipitating the sulphuric acid by chloride of barium. The sulphate of baryta goes down, and there is left in the solution chloride of potassium and chloride of aluminum. When the mass is dried, water is decomposed; hydrochloric acid is then expelled, and alumina, mixed with the chloride of potassium, remains behind; the latter is to be dissolved away by water, leaving the alumina as a white substance, which, with water, forms a plastic mass, capable of being moulded, and retaining its shape when baked. After ignition, it adheres to the tongue, and during the act of drying it contracts considerably in volume, a property which formerly gave rise to the invention of Wedgewood's pyrometer.

The presence of alumina gives to the clays those properties which fit them for the purpose of the potter and brickmaker. Alumina is also used as a mordant to fix the colors of certain dyes upon cloth.

Alumina is precipitated from its solutions by fixed alkalies, which yield a white hydrate of alumina, soluble in an excess of the precipitant. It is also thrown down by alkaline carbonates; and, when these precipitations are made in a solution tinged with coloring matter, the alumina carries it down with it. Such colored precipitates pass under

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How is aluminum prepared? What is the constitution of its oxide? Under what natural forms does it occur? How may alumina be prepared? What principle is involved in Wedgewood's pyrometer? What is meant by a mordant? How may the presence of alumina be recognized?

the name of lakes; and it is this property of attaching such colors to itself, enabling it to cause their firm adhesion to cloth fibre, which is the principle of its application as a mordant.

Among the purposes to which alumina is applied may be mentioned the manufacture of PORCELAIN, and the different kinds of earthen-ware. The former substance, first made by the Chinese, is very compact and translucent. It consists essentially of clay mixed with a fusible body, which binds all its parts together, and is covered with a glaze, which does not terminate abruptly on the surface, but pervades the substance of the mass. In this respect it differs from common earthen-ware. Feldspar, or the silicate of lime, are bodies suitable for communicating this glassy structure.

In the manufacture of porcelain, great care is taken to select clay free from iron. It is mixed with powdered quartz and feldspar, and the requisite shape given it either by the potter's wheel, or by pressing it into moulds. It is then dried in the air, and more perfectly in a furnace, and, when ignited, forms *biscuit*. This is dipped in the glaze, suspended in water, and becomes covered over with a uniform coat of it. It now remains to dry it once more, and fuse the glaze upon it.

EARTHEN-WARE consists of a white clay mixed with silica. It is glazed with a fusible material containing oxide of lead, and colored of different tints by metallic oxides; for example, blue by cobalt.

Connected with the manufacture of pottery may also be mentioned the manufacture of GLASS, of which there are several varieties, some consisting of silica, potash or soda, and lime, others containing a large quantity of oxide of lead If silica be heated with carbonate of potash and lime, or oxide of lead, carbonic acid is expelled, and glass forms. The mass is kept in a fused condition till it is free from air bubbles, and is then cooled until it becomes plastic, so that it may be blown or moulded.

Articles of glass, after they are manufactured, require to be annealed or slowly cooled down. This allows their parts to assume a regular structure, and prevents excessive brittleness.

What are lakes? What substances are used in the preparation of porcelain and earthen-ware? How is glass made? Why must it be annealed

Soluble glass is formed when silica is heated with twice its weight of carbonate of soda or potash. It derives its name from the fact that it is for the most part soluble in water.

SALTS OF THE SESQUIOXIDE OF ALUMINUM.

Sulphate of Alumina is made by dissolving alumina in dilute sulphuric acid. It enters into the composition of the alums.

Sulphate of Alumina and Potash—Alum.—This important salt is prepared from alum slate. It crystallizes in octahedrons, has an astringent taste, reddens litmus paper. It dissolves in about eighteen times its weight of cold, and less than its own weight of boiling water. It contains twenty-four atoms of water, and, when exposed to heat, foams up, melting in its own water, which, being evaporated away, leaves a white porous mass, commonly called burnt alum.

In the same way that the sulphate of potash unites with the sulphate of alumina, so also do the sulphates of ammonia and of soda, forming respectively the ammoniacal and soda alums. The alumina in the common alum may be replaced, also, by the sesquioxides of iron, manganese, or chromium, giving iron, manganese, and chrome alums.

The following metals, Glucinum, Thorium, Yttrium, Zirconium, Lanthanium, and Cerium, are very rare bodies, and, being of little interest, may be passed over without farther notice.

LECTURE LXI.

Manganese.—*Its Seven Oxides.—The Peroxide and its Applications.—Mineral Chameleon.—Acids of Manganese.—Salts of the Protoxide.*—Iron.—*Its Natural Forms.—Reduction on the Great Scale.—Cast Iron.—Wrought Iron.—Steel.—Passive Iron.*

MANGANESE. $Mn = 27{\cdot}7$.

Manganese may be procured by igniting its oxides with

What are the properties of the sulphate of alumina and potash? How may manganese be obtained? What are its properties? How many oxides does it furnish? How may manganese be detected?

a mixture of lampblack and oil in a powerful furnace, the reduction being somewhat difficult. It is a white metal, specific gravity 8·013, requiring a white heat for its fusion, and oxydizing readily in the air. It is remarkable for the number of oxygen compounds which it yields; they are

$$MnO \ldots Mn_2O_3 \ldots MnO_2 \ldots MnO_3 \ldots Mn_2O_7 \ldots Mn_3O_4 \ldots Mn_4O_7,$$

designated respectively,

Protoxide of manganese.
Sesquioxide of manganese.
Peroxide of manganese.
Manganic acid.
Permanganic acid.
Red oxide of manganese.
Varvicite.

Of these, the protoxide may be made by passing hydrogen gas over red-hot peroxide of manganese. It is of a green color, is a basic body, and forms a series of salts, of which the sulphate is used in dyeing. It is isomorphous with magnesia and zinc. Hydrosulphuret of ammonia yields with it a flesh-colored precipitate, ferrocyanide of potassium a white, and the chloride of soda a dark brown hydrated peroxide. The sesquioxide is made by igniting the peroxide, as will be presently explained. The red oxide and varvicite occur as minerals; but of the whole series the peroxide is by far the most valuable.

Peroxide of Manganese, $MnO_2 = 43{\cdot}726$,

is found abundantly as a mineral, and passes in commerce under the name of black oxide of manganese, a name indicating its color. It is insoluble in water, and, when exposed to a red heat, gives off one fourth of its oxygen, forming the sesquioxide, as stated above, the action being

$$2(MnO_2) \ldots = \ldots Mn_2O_3 + O.$$

On this fact is founded one of the processes for obtaining oxygen gas. Heated with hydrochloric acid, it yields chlorine, as has been explained. It was formerly called glassmakers' soap, from the circumstance that it removes, when added to melted glass, the stain of protoxide of iron, by turning it into peroxide, and causes the glass to become colorless; but if too great a proportion of peroxide of manganese is used, the glass assumes an amethystine color.

Peroxide of manganese, when ignited with caustic potash in a platina crucible, yields a substance known as *Mineral*

What is the constitution of the peroxide? What color does it give to glass?

Chameleon, which is of a green color. Water dissolves from it the *Manganate of Potash*, which is of a beautiful grass green, the solution speedily passing through a variety of shades of purples, blues, and reds. As yet, manganic acid is a hypothetical compound, and has not been insulated. When mineral chameleon is dissolved in hot water, a red solution is obtained of the *Permanganate of Potash;* from the permanganate of baryta a crimson solution of *Permanganic Acid* may be procured by the aid of sulphuric acid; but permanganic acid can not be obtained in the solid form.

Among other compounds of manganese, the following may be named:

Protochloride of manganese	$MnCl$	=	63·15.
Perchloride " "	Mn_2Cl_7	=	303·19.
Perfluoride " "	Mn_2Fl_7	=	186·46.

The protochloride may be made by acting on the peroxide with muriatic acid, evaporating to dryness, and fusing at a red heat. On digesting with water, the protochloride dissolves, and any impurity of iron is left in the state of oxide. Then, by crystallizing, the chloride can be obtained in pink crystals. The perchloride is produced when permanganate of potash, common salt, and sulphuric acid are heated. It is a dark greenish and volatile liquid. The perfluoride is obtained by distilling sulphuric acid, permanganate of potash, and fluor spar; it is a greenish yellow gas.

SALTS OF THE PROTOXIDE OF MANGANESE.

Protosulphate of Manganese, formed by dissolving protoxide of manganese in sulphuric acid. The figure of its crystals depends on the temperature at which they were formed. They have a rose-colored tint. It is insoluble in alcohol, very soluble in water, and is used by the dyers to produce a fine brown color.

There is but one sulphuret of manganese. It is obtained as a hydrate when manganese is precipitated by hydrosulphuret of ammonia (MnS, HO). It is of a flesh-red color

IRON. $Fe = 28·00$.

Iron sometimes occurs in a native state and as meteoric iron, also as oxide, carbonate, sulphuret, &c. It is one of

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How is mineral chameleon made? What are its properties? Can manganic acid be isolated? How may the chlorides of manganese be formed? What are the properties of the fluoride? What is the formation and use of the protosulphate of manganese?

the most abundant of the metals. Much of what is found in commerce is derived from clay iron-stone, which is an impure carbonate containing silica, alumina, magnesia, and other foreign substances. The native peroxide of iron, red hæmatite; the hydrated peroxide, brown hæmatite; the black oxide, or magnetic iron ore, furnish some of the finer varieties of the metal.

From *clay iron-stone* metallic iron is procured by the action of carbonaceous matter and lime at a high temperature. The ore, having been roasted, is thrown into the furnace with coal and lime. If the iron is in the ore as a silicate, the lime decomposes it at those high temperatures, forming a slag of silicate of lime, and the oxide of iron set free is instantly reduced by the carbonaceous matter; the metal sinking down, protected by the slag, is let off by opening a hole in the bottom of the furnace.

The substance thus produced is not pure iron; it contains carbon and other impurities, and passes under the name of cast or pig iron. It is purified by melting and sudden cooling, which converts it into *fine metal;* this fine metal is then melted under exposure to air, which burns off the carbon as carbonic oxide, and the mass, from being perfectly fluid, becomes coherent. It is now subjected to violent mechanical action, such as hammering or rolling; this forces out or burns off the impurities, increases its tenacity, and it becomes the wrought iron of commerce.

Cast Iron melts readily at a bright red heat, and expands in solidifying; on this depends its valuable application for making castings. Kept under the surface of salt water for a length of time, cast iron becomes converted into a body somewhat like plumbago, due, probably, to the removal of the iron as a chloride; the carbon which is left behind is sometimes observed, as it dries, to become hot: a phenomenon to be accounted for by its porous state. These facts have been frequently verified in the case of cannon which have lain for years at the bottom of the sea. There are two forms of cast iron, white and gray; the former contains about five per cent. of carbon, the latter three or four.

Pure Iron may be obtained by decomposing precipitated peroxide of iron by hydrogen gas, and melting the result.

What are the forms under which iron chiefly occurs? How is it obtained from clay iron-stone? What is cast iron? By what processes is it converted into wrought iron? What are the properties of cast iron? What changes does it undergo under water? How may pure iron be obtained?

The metal has a bluish color, is more ductile than malleable, and is the most tenacious of all bodies. It becomes very soft at a red heat, and possesses the welding property; on this depends the art of forging it. Its specific gravity is 7·7. It is one of the few magnetic bodies, and, when soft, its magnetism is so transient that it may gain and lose that quality a thousand times in a minute. The melting point of iron is very high. In the mode of preparing it from cast iron it does not undergo the process of fusion, but its particles are simply welded together. The fibrous structure which wrought iron possesses is the chief cause of its great tenacity; a wire $\frac{1}{36}$th of an inch in diameter will bear a weight of 60 pounds.

Steel, which is a valuable preparation of iron, is made by placing alternate strata of iron bars and charcoal powder in a close box and keeping them red hot. The process is known by the name of cementation. The iron gains about 1·5 per cent. of carbon. Steel is much more fusible than iron, and becomes excessively hard and brittle by being brought to a red heat and then suddenly quenched in cold water. When allowed to cool slowly, it is quite soft, and various degrees of elasticity and hardness may be given to it by the process of tempering.

By placing a piece of platina in nitric acid of a specific gravity of 1·94, and then bringing an iron wire in contact with it and withdrawing the platina, the iron assumes a passive or allotropic state. It now exhibits no tendency to unite with oxygen, can not precipitate copper from its solutions, and simulates the properties of platina and gold.

LECTURE LXII.

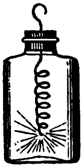
IRON.—*Oxides of.—Three Oxides and Ferric Acid.—Tests for Iron.—Salts of the Protoxide and Peroxide.—The Sulphurets.*—NICKEL.—*Its Reduction from the Oxalate.*—COBALT.—*Smalt.—Zaffre.—Sympathetic Ink.*—ZINC.—*Distillation of.—Salts of the Protoxide.*

IRON AND OXYGEN.

IRON burns with rapidity in oxygen gas, as may be proved

What are its properties? What is steel? How is it made, and what are its properties? How may iron be rendered passive?

Fig. 269.



by igniting a piece of it in wire coiled into a spiral form in a jar of that gas (*Fig.* 269), when it will be found to take fire and burn beautifully. In atmospheric air, under favorable circumstances, the combustibility of this metal may be proved. Thus, fine iron filings, sprinkled in the flame of a spirit lamp, burn with scintillations ; exposed to air and moisture, it slowly rusts. Iron yields four oxides:

Protoxide . . . . $FeO = 36{\cdot}013$.
Black oxide . . . $Fe_3O_4 = 116{\cdot}052$.
Peroxide . . . . $Fe_2O_3 = 80{\cdot}039$.
Ferric acid . . . . $FeO_3 = 52{\cdot}039$.

Protoxide of Iron. $FeO = 36{\cdot}013$.

This oxide has not yet been insulated, but it exists, united with acids, in an extensive series of salts, from which it is thrown down as a hydrate by alkalies, and is then of a white color, which darkens as it passes into the state of peroxide. Ferrocyanide of potassium gives a white precipitate, and the ferridcyanide a deep blue. Hydrosulphuret of ammonia gives a black sulphuret of iron. Sulphureted hydrogen and gallic acid give no precipitate.

Black Oxide of Iron. $Fe_3O_4 = 116{\cdot}052$.

This oxide, known also as the magnet or loadstone, is found as a mineral. It is a compound of the protoxide and peroxide. The scales of iron found in blacksmiths' forges mainly consist of it. It may also be produced by decomposing the vapor of water by metallic iron in a red-hot tube.

Peroxide of Iron, $Fe_2O_3 = 80{\cdot}039$,

is found in nature as oligist iron, or as a hydrate. It may be produced artificially as a hydrate by precipitation from a solution of persulphate of iron by a caustic or carbonated alkali, or in a pure state by igniting green vitriol; there is then left a red powder, known as *rouge*, used for polishing metals. This oxide is not magnetic; it is the basis of a series of salts which yield, with alkalies, a brown hydrated peroxide ; with ferrocyanide of potassium, Prussian blue ;

How may the rapid oxydation of iron be illustrated ? How many oxides does this metal yield ? What are the reactions which the protoxide furnishes with tests ? Under what natural forms does the black oxide occur? How may it be formed artificially ? What are the natural forms of the peroxide ? How may it be prepared ? For what purposes is it used ? What is its action with reagents ?

with sulphocyanide of potassium, a blood-red solution; with tannin and gallic acid, a black. This last is of considerable interest, constituting the basis of ordinary ink.

The presence of iron can always be determined by passing it into the condition of peroxide, and applying the foregoing tests.

Ferric Acid, $FeO_3 = 52{\cdot}039$,

is prepared by heating peroxide of iron with four parts of nitrate of potash. The result is treated with cold water, which yields a red solution of the ferrate of potash. This slowly decomposes in the cold, and very rapidly when the solution is warm. The ferrate of baryta precipitates when the potash solution is acted on by a soluble salt of baryta. It is a permanent body, of a crimson color.

Among other compounds of iron, the following may be named:

Protochloride of iron	. . . . . .	$FeCl$	$= 63{\cdot}47$
Perchloride "	. . . .	Fe_2Cl_3	$= 162{\cdot}35$
Protiodide "	. . . .	FeI	$= 153{\cdot}57$
Protosulphuret "	. . . .	FeS	$= 44{\cdot}12$
Sesquisulphuret "	. . . .	Fe_2S_3	$= 104{\cdot}36$
Bisulphuret "	. . . .	FeS_2	$= 60{\cdot}24$

Of these, the protochloride is formed by passing hydrochloric acid over red-hot iron. It is white, but forms a green solution in water. The perchloride, in solution, by dissolving peroxide of iron in hydrochloric acid. The protiodide, by boiling an excess of iron filings with iodine, and evaporating; it forms, on cooling, a dark gray mass. Its solution absorbs oxygen from the air. The protosulphuret of iron, which is much used for forming sulphureted hydrogen, may be made by heating a mass of iron to a white heat, and applying to it roll sulphur, and receiving the melted globules in a bucket of water. It may also be procured by igniting iron filings with sulphur. The bisulphuret occurs abundantly as a mineral of a golden yellow color, crystallized in cubes or allied forms, and known as *Iron Pyrites*. It frequently assumes the form of various organic remains, being one of the common petrifying agents, but in this state differs essentially from the cubic pyrites, both in color and oxydizability; these fossil remains rapidly decaying under exposure

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What is common ink? How may the presence of iron be detected? What are the properties of ferric acid? Of the other compounds, mention some of interest. What is iron pyrites? What is the difference of its forms?

to the air, but the other form being unacted on. **Besides** these, there is a sulphuret of iron which is magnetic.

SALTS OF THE PROTOXIDE OF IRON.

Carbonate of Iron may be obtained from the sulphate by an alkaline carbonate, falling as a whitish precipitate. It turns brown, however, from the absorption of oxygen. It occurs as a mineral in spathic iron, and dissolves in water containing carbonic acid, forming chalybeate waters.

Protosulphate of Iron—Copperas—Green Vitriol—is prepared largely by the oxydation of iron pyrites, and crystallizes in oblique prisms of a grass-green color. It has a styptic taste, dissolves in twice its weight of cold, and three fourths its weight of boiling water. It contains five atoms of water. At a low red heat it becomes anhydrous. In this state it is used for the manufacture of the Nordhausen sulphuric acid.

SALTS OF THE PEROXIDE OF IRON.

Persulphate of Iron may be formed by adding to a solution of the protosulphate of iron half an equivalent of sulphuric acid, and peroxydizing by nitric acid. With water it forms a red solution.

NICKEL. $Ni = 29{\cdot}5$.

Nickel may be obtained by igniting its oxalate in a covered crucible, carbonic acid escaping, and the metal being reduced.

$$NiO + C_2O_3 \ldots = \ldots Ni + 2(CO_2);$$

one atom of the oxalate of nickel yielding one of the metal and two of carbonic acid gas.

Nickel is a white metal, requiring a high temperature for fusion. It is magnetic, and has a specific gravity of 8·5. It is commonly associated with iron in meteorites, and enters into the composition of German silver; unites with oxygen, forming a protoxide and sesquioxide, the former yielding salts of a green color; the latter is an indifferent body

SALTS OF THE PROTOXIDE OF NICKEL.

Sulphate of Nickel crystallizes from its solutions with six atoms of water in slender green prisms, which, when ex-

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How is carbonate of iron formed? What is the process for preparing the sulphate? How is the persulphate obtained? By what process is nickel obtained? What are its properties? Under what remarkable circumstances does it occur with iron?

posed to the sun, change into an aggregate of octahedrons, becoming opaque.

Nickel is chiefly used in the preparation of German silver, an alloy of copper, zinc, and nickel. It is of a white color, takes a good polish, and is malleable.

COBALT, $Co = 29{\cdot}5$,

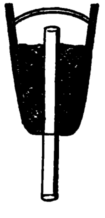
is generally associated with iron and nickel, and with them occurs in meteoric iron. Like the preceding metal, it may be obtained by igniting its oxalate in a covered crucible, carbonic acid being disengaged and metallic cobalt left. It is a pinkish white metal, requiring a high temperature for fusion. Its specific gravity is 7·8. It is magnetic, as recent experiments have proved. It forms a protoxide and a sesquioxide, the former being the basis of a class of salts which are chiefly of a pink or blue color. *Smalt* is a silicate of cobalt, and *Zaffre* an impure oxide; the former is used to communicate to paper a faint blue tinge, and the blue color which the oxide gives to glass is taken advantage of in coloring the common varieties of earthen-ware. Cobalt is easily detected upon this principle.

The chloride of cobalt may be made by dissolving the oxide or the metal in hydrochloric acid. It is a pink solution, which turns blue when dried. It forms a beautiful *sympathetic ink*, for letters written with it, especially on paper which has a pinkish tinge, are entirely invisible, but become of a bright blue color when the paper is warmed, the letters again fading as they become cool and moist.

ZINC. $Zn = 32{\cdot}3$.

ZINC is a very abundant metal, immense quantities of it occurring in the state of New Jersey and in various other places. From zinc blende, which is a sulphuret, converted by roasting into an oxide, or from the carbonate brought into the same state by ignition, the metal may be obtained by the process of distillation by descent. The oxide, mixed with charcoal, is introduced into a crucible which has an iron tube passing through a hole in its bottom, as seen in *Fig.* 270, and the

Fig. 270.



What change does the sulphate of nickel undergo in the sunlight? How is cobalt procured? Is it magnetic like nickel? What is smalt? What is zaffre? What are the uses of cobalt? What property does the chloride possess? By what process is zinc obtained?

lid being luted on, the temperature is raised to a white heat, and the zinc, distilling over, may be condensed in water.

Zinc is a bluish-white metal, which melts at about 770° F., and, if exposed at a bright red heat to the air, takes fire and burns with a brilliant pale green flame. Its specific gravity is about 7·00. At common temperatures it is brittle, but it may be rolled into thin sheets at about 300° F., and then retains its malleability when cold. During its combustion there arises from it a great quantity of flocculent oxide, which formerly went under the name of *nihil album*, or philosopher's wool. Among the compounds of zinc may be mentioned

Protoxide of zinc . . . . $ZnO = 40{\cdot}313$.
Chloride " . . . . $ZnCl = 67{\cdot}75$.
Sulphuret " . . . . $ZnS = 48{\cdot}4$.

Of these, the oxide is formed, as has been said, during the combustion of zinc. It is also precipitated as a white hydrate from its soluble salts by potash or soda, soluble in excess of the precipitant. The chloride may be made by the action of hydrochloric acid on metallic zinc. It is used in the arts for soldering under the name of butter of zinc. The sulphuret occurs as a mineral under the name of zinc blende.

SALTS OF THE PROTOXIDE OF ZINC.

Sulphate of Zinc—White Vitriol.—This salt is formed in the process for procuring hydrogen gas by the action of dilute sulphuric acid on zinc. It crystallizes in colorless prisms with six atoms of water, and is soluble in two and a half parts of cold water. It has a styptic taste, and reddens vegetables blues. There are three different subsulphates of this oxide.

Silicate of Zinc, the electric calamine of mineralogists; remarkable for becoming electric when heated.

Is there any connection between the ductility of zinc and its temperature. During combustion, what arises from it? How may it be detected? How is white vitriol prepared? What is electric calamine?

LECTURE LXIII.

CADMIUM.—*Sources of.—Its Volatility.*—TIN.—*Block and Grain.—Its Properties.—Protoxide and Stannic Acid.—Chlorides of Tin.—Mosaic Gold.—Its Uses.*—CHROMIUM.—*Chromiron.—Green Oxide and its Uses.—Chromic Acid.—Salts of the Sesquioxide.—Salts of Chromic Acid.—Other Metals.*—TITANIUM.

CADMIUM. $Cd = 55{\cdot}8$.

CADMIUM usually occurs associated with zinc as a carbonate. In the preparation of that metal by distillation, as has been described, the cadmium first comes over. From any impurity of zinc it may be separated by precipitation from an acid solution by sulphureted hydrogen, which throws the cadmium down as a yellow powder, but does not act on the zinc. The sulphuret of cadmium is then dissolved in nitric acid, the oxide precipitated by potash, and, when dry, reduced by charcoal. The compounds of cadmium are not important. The metal itself is very volatile.

TIN. $Sn = 57{\cdot}9$.

TIN occurs as an oxide in England, Mexico, Germany, and the East Indies. It may be reduced by the action of charcoal at a high temperature. It is found in commerce under two forms, block tin and grain tin. If a bar of tin is heated, the purer parts, being the more fusible, ooze out of it, constituting grain tin, and the mass which is left behind is block tin.

Tin is a white metal like silver. It oxydizes in the air superficially, the action ceasing as soon as a thin crust is formed. At a red heat it oxydizes rapidly, forming *putty powder*, used for polishing metals. It is very malleable, and may be rolled into thin foil. When bent backward and forward it emits a crackling sound. It is very soft; its specific gravity 7·2. It melts at 442°, and burns when raised to a high temperature in the air. Some of its compounds are

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Under what circumstances does cadmium occur? What are the native forms of tin? What are block and grain tin? What are the properties of tin? When a bar of tin is bent backward and forward, what phenomenon arises?

Protoxide of tin	SnO	= 65·913.
Sesquioxide	Sn_2O_3	= 129·839.
Peroxide	SnO_2	= 73·926.
Protochloride	$SnCl$	= 93·37.
Perchloride	$SnCl_2$	= 128·74.
Protosulphuret	SnS	= 74·
Persulphuret	SnS_2	= 90·1.

The protoxide may be made by precipitation from the protochloride by carbonate of potash. It is to be washed with warm water, and its water finally driven off in a current of carbonic acid gas at a red heat. It is of a black color, is easily set on fire in atmospheric air, passing into the condition of peroxide. Its salts reduce the noble metals to the metallic state, when added to their solutions, and yield with the chloride of gold *the Purple of Cassius.* The peroxide, called also stannic acid, from exhibiting weak acid properties, may be made by the action of nitric acid on tin. It is a hydrate in the form of a white powder, insoluble in acids and water; but if obtained by precipitation from perchloride of tin, it is soluble both in acids and alkalies Melted with glass, it forms a white enamel.

The protochloride may be made by dissolving tin in warm hydrochloric acid. The solution, when concentrated, deposits crystals of the hydrated potochloride. These are decomposed when heated. The anhydrous protochloride may be had by passing hydrochloric acid gas over metallic tin at a red heat. The perchloride is procured by distilling eight parts of tin with twenty-four of corrosive sublimate. It is a smoking fluid, and was formerly called the *Fuming Liquor of Libavius.* A solution of this substance, much used in dyeing, is made by dissolving tin in nitro-muriatic acid, or by warming a solution of the protochloride with a little nitric acid.

Of the sulphurets, the first may be formed by pouring melted tin on sulphur, and igniting the powdered result with more sulphur in a crucible. It is a bluish gray compound. The persulphuret is obtained when two parts of peroxide of tin, two of sulphur, and one of sal ammoniac are ignited in a retort. It is a body of a golden yellow color, formerly called *Aurum Musivum*, or Mosaic gold, in small scales of a greasy feel, and is used for exciting elec-

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How is the protoxide made, and how do its salts act on those of the noble metals? How is stannic acid prepared? What does it yield with glass? What is the fuming liquor of Libavius? How is mosaic gold made, and what is its use?

trical machines, being much more energetic than the common amalgam, though less durable in its power.

Tin furnishes several valuable metallic combinations: *Tin Plate* is sheet iron superficially alloyed with it. The *soft solders* are alloys of lead and tin. *Pewter* is an alloy with antimony.

CHROMIUM. $Cr = 28$.

Chromium occurs abundantly near Baltimore as the chromate of iron (*Chrome Iron*), more rarely as the red chromate of lead. The metal may be obtained by the action of charcoal on the oxide at a high temperature, and is of a yellowish-white color. It takes its name from its tendency to produce highly colored compounds. It is very infusible, and has a specific gravity of about 6·00. Its compounds, to be here described, are

Sesquioxide of chromium . . . . $Cr_2O_3 = 80{\cdot}039$.
Chromic acid . . . . $CrO_3 = 52{\cdot}039$.
Sesquichloride of chromium . . . . $Cr_2Cl_3 = 162{\cdot}26$.

The sesquioxide may be prepared by heating the chromate of mercury to redness in a crucible. The mercury is driven off, and the chromic acid partially deoxydized, leaving a beautiful grass-green powder, the sesquioxide. It may also be obtained by heating the bichromate of potash red hot, and washing the residue in water; also as a hydrate, by boiling a solution of bichromate of potash with muriatic acid, and adding alcohol; the mixture becomes of a green color, and ammonia precipitates the hydrated sesquioxide. It is a weak base, yielding a class of salts of a blue or green color. In the state of hydrate it is soluble in acids; but, on making it red hot, it suddenly becomes incandescent, passes into another allotropic state, and is now insoluble. This sesquioxide is isomorphous with the sesquioxides of iron and alumina. In its two allotropic states it yields corresponding classes of salts, one of which is green, and the other reddish green. It is used for communicating a green color to porcelain.

Chromic Acid may be made by adding one volume of a saturated solution of bichromate of potash to one and a half of oil of vitriol. On cooling, red crystals of chromic acid are deposited. It is isomorphous with sulphuric acid, pro-

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What alloys does tin furnish? Under what forms does chromium occur in nature? How is its sesquioxide prepared, and what is its use? How is chromic acid made?

duces with bases yellow and red salts, is a powerful oxydizing agent, is decomposed by a red heat into the sesquioxide, destroys the color of indigo and other dyes, and may be detected by producing with the salts of lead, chrome yellow, and by its ready passage, under the influence of deoxydizing agents, into the sesquioxide.

The sesquichloride is procured when chlorine is passed over a mixture of the sesquioxide and charcoal in a red-hot tube. It is a lilac-colored body, which forms a green solution in water. There is also an oxychloride, which may be distilled as a deep-red liquid from a mixture of chromate of potash, common salt, and oil of vitriol. The fluoride, which is a red gas, is obtained by distilling in a silver retort a mixture of chromate of lead, fluor spar, and oil of vitriol. It is decomposed by the moisture of the air, forming chromic and hydrofluoric acids.

SALTS OF THE SESQUIOXIDE OF CHROMIUM.

Sulphate of Chromium and Potash—Chrome Alum. —When the oxide of chromium is dissolved in sulphuric acid, and mixed with the sulphate of potash and a little free sulphuric acid, crystals of chrome alum are deposited in red or blue octahedrons. The sulphate of chromium alone does not crystallize.

Chrome Iron, a compound of the sesquioxide of chromium and the protoxide of iron, is found native, crystallized in octahedrons, and also massive. It furnishes most of the compounds of chromium.

SALTS OF CHROMIC ACID.

Chromate of Potash may be made by igniting chrome iron with one fifth its weight of nitrate of potash. It crystallizes in small, lemon-yellow prisms, and is very soluble in hot water. The crystals are anhydrous.

Bichromate of Potash may be prepared from the former by adding an equivalent of acetic acid: it crystallizes in prisms of a ruby red. Large quantities are consumed by dyers.

Chromate of Lead—Chrome Yellow, obtained by pre-

Does chromic acid possess bleaching powers? How are the chloride and fluoride obtained? What is the form of the latter body? What is chrome alum? What is the constitution of the two chromates of potash? What is chrome yellow?

cipitation from either of the foregoing salts by a soluble salt of lead. It is used as a paint.

Dichromate of Lead is formed by adding chromate of lead to melted nitrate of potash, and dissolving out the chromate of potash and excess of nitre by water. It is of a beautiful red color.

The following metals, VANADIUM, TUNGSTEN, MOLYBDENUM, OSMIUM, and COLUMBIUM, are not applied to any purposes in the arts, or are so rare as not to be of general interest. TITANIUM might be included in the same observation; it is, however, deserving of remark, as being a red metal like copper, and titanic acid, one of its oxygen compounds, is used in the coloring of artificial teeth.

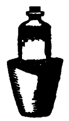
LECTURE LXIV.

ARSENIC.—*Preparation of the Metal.—Properties of Arsenious Acid.—Two Varieties of it.—Two methods of detecting it.—Process in Cases of Poisoning.—Sulphureted Hydrogen Test.—Marsh's Test.—The Copper Test.—Difficulties arising from Antimony.*

ARSENIC. $As = 37{\cdot}7$.

ARSENIC is obtained by sublimation in a current of air of the arseniuret of cobalt and iron, the vapor condensing as a white oxide. This being mixed with powdered charcoal or black flux, and heated, the metallic arsenic sublimes. The process may be conducted in a tall vial imbedded in a crucible filled with sand, two thirds of the vial projecting above the heated sand. On this cooler portion the metal condenses. It is also sometimes found in a native state.

Fig. 271.



Arsenic is a metallic body, of an aspect darker than cast iron; it is very brittle, its specific gravity is 5·88, and, when slowly sublimed, it crystallizes in rhombohedrons. At 356° F. it sublimes without undergoing fusion, its melting point being much higher than that of sublimation. Its vapor has a smell of garlic, as may be readily recognized by

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What is the color of titanium? From what substances, and in what manner, is arsenious acid prepared? How is the metal obtained from it? What are its properties? Why can not it be melted? What is the odor of its vapor?

throwing a little arsenious acid on a red-hot coal. Arsenic prepared by black flux tarnishes, it is said, from containing a little potassium. Among its compounds, the following may be mentioned:

Arsenious acid	$As_2O_3 = 99·439.$
Arsenic acid	$As_2O_5 = 115·465.$
Protosulphuret of arsenic . . .	$AsS = 53·8.$
Sesquisulphuret of arsenic . .	$As_2S_3 = 123·7.$
Arseniureted hydrogen	$AsH = 38·7.$

Arsenious Acid is formed when arsenic is sublimed in atmospheric air. It is a white substance, which, when the process is conducted slowly, crystallizes in octahedrons. Similar octahedral crystals may be obtained by heating arsenious acid itself in a tube to 380° F. When the operation has been recently performed and a large mass sublimed, it is a glassy, transparent body, which in the course of time slowly becomes milk-white. The specific gravity of arsenious acid is 3·7. It is nearly tasteless, of sparing solubility in water, the two varieties differing in this respect. By 100 parts of water, 11·5 of the opaque, but only 9·7 of the transparent, are dissolved. This substance passes currently under the name of arsenic. It ought not to be forgotten that the arsenic of chemical writers and that of commerce are very different bodies: the one is black and the other white; the one is a metal and the other its oxide.

Arsenious acid may be detected by several methods:

1st. With ammonia sulphate of copper, it gives an emerald green precipitate; the arsenite of copper, or Scheele's green.

2d. With the ammonia nitrate of silver, a canary yellow precipitate; the arsenite of silver.

3d. With sulphureted hydrogen, a solution, previously acidulated with acetic or muriatic acid, yields a yellow precipitate, the sesquisulphuret of arsenic, orpiment. This, when dried and ignited with black flux (a mixture of charcoal and carbonate of potash, obtained by igniting cream of tartar in a covered crucible), yields a sublimate of metallic arsenic.

From the metal, how may arsenious acid be procured? What change does the glassy variety undergo in time? Of these varieties, which is most soluble in water? What is the difference between the arsenic of chemists and the arsenic of commerce? What is the action of ammonia sulphate of copper on arsenious acid? What of the ammonia nitrate of silver? What of sulphureted hydrogen?

4th. With the materials for generating hydrogen gas; that is, sulphuric acid, zinc, and water, placed in a bottle; if arsenious acid be present, arseniureted hydrogen is disengaged. When set on fire, it burns with a pale blue flame, emitting a white smoke; and if a piece of cold glass be held in the flame, there is deposited upon it a black spot of arsenic, surrounded by a white border of arsenious acid. This stain is volatilized on heating the glass. Or if the arseniureted hydrogen be conducted through a tube of Bohemian glass, made red hot at one point by a spirit lamp, it is decomposed, and metallic arsenic deposited on the cooler portions beyond the ignited space.

5th. If a solution containing arsenious acid be acidulated with hydrochloric acid, and boiled with slips of copper, the metallic arsenic is deposited upon the copper as an iron gray crust.

In cases of poisoning by this substance, it is unsatisfactory to apply, in the first instance, color-giving tests, such as the first, second, and third, as the liquor obtained from the stomach is itself highly colored and turbid. It is, therefore, desirable to examine that organ and its contents minutely, endeavoring to discover any white granules, or specks, which may be supposed to be arsenious acid, and if such are found, to examine them separately.

The contents of the stomach, the larger pieces having been divided, are to be boiled in water, and strained through a linen cloth. A current of chlorine gas passed through this liquid coagulates and separates much of the animal matter; or, what is more convenient, if the solution be first acidulated with nitric acid, and then nitrate of silver be added, much of the animal matter may be removed. By the addition of a solution of common salt, the excess of the silver salt may be precipitated, and the liquor being filtered, is then fit for the third or fourth of the foregoing tests.

In the application of sulphureted hydrogen, the liquor having been clarified as just stated, the gas is passed through it until it smells strongly. It is then to be boiled for a short time, to expel the excess of gas, and filtered. The yellow precipitate of sesquisulphuret of arsenic, or orpiment, which

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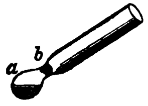
What is the process for detecting it by arseniureted hydrogen? What is that by copper? In cases of poisoning, why can not color tests be applied? How is the liquid obtained from the stomach to be clarified? Describe the test by sulphureted hydrogen.

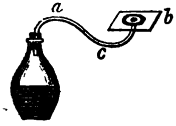
is collected, is to be thoroughly dried, and introduced, with twice its bulk of black flux, into the bulb, *a*, of a tube, such as *Fig.* 272, made of hard glass. On the temperature being raised by a lamp, metallic arsenic sublimes, forming an iron black ring round the part *b*. By cutting off the bulb of the tube and heating the black crust gradually, it slowly sublimes toward the colder part, producing a white deposit of arsenious acid in octahedral crystals.

Fig. 272.



In the application of *Marsh's test*, the liquor, having been cleared either by chlorine or by nitrate of silver, as above described, is to be introduced into a bottle containing dilute sulphuric acid and zinc, a tube, bent as represented in *Fig.* 273, *a*, passing laterally from the cork; arseniureted hydrogen now passes off, and may be set on fire as it escapes from the end of the tube, and examined by holding in the flame a piece of cold glass, *b*. If no spot be produced, then the tube, which for this reason should be made of a hard glass not containing lead, is to be ignited by a spirit lamp at the point *c*, and the gas will deposit its arsenic a little beyond that point. In this manner, the tube being kept red hot for hours, the smallest quantity of arsenic may be discovered.

Fig. 273.



If the liquor, notwithstanding the care taken to clear it, froths when the hydrogen is disengaged, so as to interfere with the results by choking the tube, the gas is best collected under a jar at the pneumatic trough, and may be subsequently examined.

The fifth test, by copper, may be sometimes advantageously applied to collect the arsenic from solutions; the crust upon the copper may be subsequently examined, either by sublimation or otherwise.

It is to be remembered that antimony will yield results closely resembling those of arsenic by Marsh's test; but on heating the glass plate on which the stain has been deposited, if it be arsenic, it will totally volatilize away; but if antimony, though the flame of a blow-pipe be thrown upon

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Describe Marsh's test. How may a small quantity of metal be separated from a large quantity of liquid by this test? When the liquid froths, what course is to be pursued? When may the test of copper be advantageously applied? What metal closely resembles arsenic in these respects?

it, it will not disappear, but only gives rise to a yellow oxide, which turns white on cooling.

In medico-legal investigations, it should also be remembered that, as sulphuric acid and zinc of commerce sometimes contain arsenic, it is absolutely necessary that the specimens about to be used be critically examined themselves by being tried alone before the suspected solution is added

LECTURE LXV.

ARSENIC.—*Antiseptic Quality of Arsenious Acid.—Antidote for Poisoning.—Arsenic Acid.—Isomorphous with Phosphoric Acid.—Realgar and Orpiment.—Arseniureted Hydrogen.*—ANTIMONY.—*Reduction of.—Oxides, Chlorides, and Sulphurets of.—Antimoniureted Hydrogen.—Detection of Antimony.*—TELLURIUM.—URANIUM.—COPPER.—*Reduction of.—Use of Oxide.—Detection of.—Salts of Protoxide.*

ARSENIOUS ACID possesses a remarkable antiseptic quality, and hence often preserves the bodies of persons who have been poisoned by it. Advantage is also taken of this fact by the collectors of objects of natural history in preserving their specimens.

The antidote for poisoning by arsenic is the hydrated sesquioxide of iron. It may be made by adding carbonate of soda to the muriate of iron. It should be given in the moist state, mixed with water. After being once dried, it loses much of its power. It produces an inert basic arsenite of the peroxide of iron.

Arsenic Acid is found in nature in union with various bases. It may be made by acting on arsenious acid with nitric acid, with the addition of a little hydrochloric acid, and evaporating till the nitric acid is expelled. The resulting acid contains three atoms of water, and is isomorphous with tribasic phosphoric acid. The arseniates yield, with nitrate of silver, a dark-red precipitate of the tribasic arse-

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Why is it necessary to examine the sulphuric acid and zinc employed in these experiments? Does arsenious acid possess an antiseptic quality? What is the antidote for this poison? How is it prepared? How is arsenic acid prepared? What fact arises from the isomorphism of arsenic and phosphoric acids?

niate of silver. The monobasic and bibasic forms of the acid are not known. It should not be forgotten in medico-legal inquiries respecting arsenic, that the arseniate of lime may naturally replace phosphate of lime in bone earth, and this acid substitute the phosphoric in other parts of the system.

The protosulphuret of arsenic may be obtained by melting arsenious acid with sulphur. It occurs as a mineral *Realgar*, and is a red-colored substance.

The sesquisulphuret is deposited when a stream of sulphureted hydrogen is passed through a solution of arsenious acid. It is a yellow body, and is used in dyeing; it is also known under the name of *Orpiment*.

Arseniureted Hydrogen is prepared by acting on an alloy of zinc and arsenic with dilute sulphuric acid. It is a colorless gas, burns with a blue flame, exhales an odor like garlic. Its specific gravity is 2·695. It is decomposed by chlorine, iodine, and the arsenic is separated by heat and by the rays of the sun.

ANTIMONY. $Sb = 64{\cdot}6$.

This metal occurs commonly as a sesquisulphuret in nature, from which it may be obtained by heating with iron filings, a sulphuret of iron forming, and metallic antimony subsiding to the bottom of the crucible. It may also be obtained by fusing the sulphuret with black flux, which produces a sulphuret of potassium and metallic antimony.

Antimony is a blue-white metal, of a very crystalline structure, and so brittle that it may be pulverized. It melts at 810° F. Its specific gravity is 6·7. It possesses, at high temperatures, an intense affinity for oxygen; a fragment of it the size of a pea being ignited on a piece of charcoal before the blow-pipe, and then suddenly thrown on the table, takes fire, breaking into a multitude of globules, and filling the air with fumes of the white sesquioxide. Antimony yields the following compounds:

Sesquioxide of antimony	Sb_2O_3	$= 153{\cdot}239$.
Antimonious acid	Sb_2O_4	$= 161{\cdot}252$.
Antimonic acid	Sb_2O_5	$= 169{\cdot}265$.
Sesquichloride of antimony	Sb_2Cl_3	$= 235{\cdot}46$.
Perchloride "	Sb_2Cl_5	$= 306{\cdot}3$.
Sesquisulphuret "	Sb_2S_3	$= 177{\cdot}5$
Persulphuret "	Sb_2S_5	$= 209{\cdot}7$.
Oxysulphuret "	$2Sb_2S_3 + Sb_2O_3$	$= 508{\cdot}2$.

What is realgar? What is orpiment? How may arseniureted hydrogen be made? From what source is antimony obtained? What is the process for its preparation? What are its properties?

The *Sesquioxide of Antimony* may be made by adding to an acid boiling solution of chloride of antimony carbonate of soda. It is a gray powder, and is the base of a class of salts, among which tartar emetic may be mentioned. These salts give an orange-colored precipitate with sulphureted hydrogen.

Antimonious Acid is produced by heating the oxide of antimony, or antimonic acid. It is a white powder, and unites with bases, forming antimonites.

Antimonic Acid may be prepared by acting on metallic antimony with nitric acid.

Sesquichloride of Antimony is made by dissolving one part of sulphuret of antimony in five of hydrochloric acid, and distilling. As soon as the matter which passes over becomes solid, the receiver is to be changed, and, continuing the heat, the sesquichloride is collected. It was formerly known as butter of antimony. The perchloride may be made by burning antimony in chlorine gas. The oxychloride is produced when the sesquichloride is placed in contact with water. It was formerly known as powder of algaroth.

The *sesquisulphuret* occurs abundantly as a mineral, as has been said. It is also formed by the action of sulphureted hydrogen on the salts of the oxide of antimony. In this case it is of an orange color, in the former it has a metallic aspect. The *persulphuret* is procured when the sesquisulphuret and sulphur are boiled in a solution of potash, the liquor filtered, and an acid added, a yellow precipitate going down. It was known formerly as the *Golden Sulphuret of Antimony*. The oxysulphuret occurs native as the red ore of antimony, and may also be made by boiling the sesquisulphuret with a solution of potash. On cooling, precipitation of it takes place. It is stated, however, by Berzelius, that this is not a true compound, but merely a mechanical mixture of the oxide and sulphuret in irregular proportions. This precipitate is also known under the name of *Kermes Mineral*. From the liquor, after the kermes is separated, an acid throws down the golden sulphuret of antimony.

What color is the precipitate yielded by the salts of the sesquioxide and sulphureted hydrogen? How is antimonious acid prepared? What is the butter of antimony? What is the powder of algaroth? What is the aspect of the native sesquisulphuret? What is the golden sulphuret? What is kermes minerl?

Antimoniureted Hydrogen.—When hydrogen is evolved from a solution containing tartar emetic (tartrate of antimony and potash), this substance is produced. It is a gas, having a superficial resemblance to arseniureted hydrogen, and when used as in Marsh's apparatus, gives a stain on glass resembling that of arsenic. From arsenic it may be distinguished by not being volatile.

The soluble salts of antimony may be distinguished by giving an orange precipitate with sulphureted hydrogen, soluble in sulphuret of ammonium, but again precipitated by an acid.

Antimony furnishes some valuable alloys: printer's type metal, for example, is an alloy of this substance with lead. It expands in the act of solidifying, and therefore takes accurate impressions of the interior of a mould.

TELLURIUM. $Te = 64{\cdot}2$.

Tellurium is a rare metal, of a white color, very fusible and volatile, having several analogies with selenium, and uniting with hydrogen to form tellureted hydrogen, which, with water, yields a claret-colored solution.

URANIUM, $U = 217$,

is likewise a very rare metal, of the nature of which there are considerable doubts, it being supposed that what was formerly regarded as the metal is in reality its protoxide. It may be remarked, if these observations are incorrect, that uranium has the highest equivalent of any of the elementary bodies. It is used to a small extent to give black and yellow colors to porcelain.

COPPER. $Cu = 31{\cdot}6$.

Copper is often found native, and in certain parts of the United States in masses of very great magnitude. It also occurs as a carbonate and sulphuret. In the latter combination, it is found with the sulphuret of iron, as yellow copper ore. This being roasted, the sulphuret of iron changes into oxide, the copper sulphuret remaining unchanged. The mass is then heated with sand, which yields a silicate of iron, the sulphuret of copper separating.

How is antimoniureted hydrogen made? How may the salts of antimony be distinguished? What are the properties of tellurium? What is remarkable as respects the alleged atomic weight of uranium? Under what forms does copper naturally occur? What is the process for its reduction?

This process is repeated until all the iron is parted; and now the sulphuret of copper begins to change into the oxide, which is finally decomposed by carbon at a high temperature.

Copper is a red metal, requiring a high temperature for fusion. Its specific gravity is 8·617. It has great tenacity, and is ductile and malleable. A polished plate of it, heated, exhibits rainbow colors, and is finally coated with the black oxide. It is one of the best conductors of heat and electricity. Among its compounds, the following may be mentioned:

Protoxide of copper	. . . . . CuO	$= 39{\cdot}613.$
Suboxide "	. . . . . Cu_2O	$= 71{\cdot}213.$
Chloride "	. . . . . $CuCl$	$= 66{\cdot}02.$
Dichloride "	. . . . . Cu_2Cl	$= 98{\cdot}62.$
Disulphuret "	. . . . . Cu_2S	$= 79{\cdot}32.$

Protoxide of Copper may be made either by igniting metallic copper in contact with air, or by calcining the nitrate. It is a black substance, not decomposable by heat, but yielding oxygen with facility to carbon and hydrogen, and hence extensively used in organic analysis. It is a base, yielding salts of a blue or green color. The suboxide, called, also, red oxide, occurs native as ruby copper. It is a feeble base. The disulphuret also occurs native, as copper pyrites.

Copper is easily detected. Caustic potash gives, with its protosalt, a pale blue hydrate, which turns black on boiling. Ammonia, in excess, yields a beautiful purple solution; ferrocyanide of potassium, a chocolate-brown precipitate; sulphureted hydrogen, a black; and metallic iron, as the blade of a knife, precipitates metallic copper.

SALTS OF THE PROTOXIDE OF COPPER.

Carbonate of Copper.—The neutral carbonate of copper is not known; but there are several varieties of dicarbonates. One, which passes under the name of *Mineral Green*, is formed by precipitating with an alkaline carbonate. It occurs naturally in the form of *Malachite*. *Blue copper ore* is another dicarbonate; the paint called *Green Verditer* has a similar composition.

Sulphate of Copper—Blue Vitriol—is prepared for commerce by the oxydation of the sulphuret of copper. It crys-

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What are its properties? Which of its oxides is used in organic analysis? How may copper be detected? Under what forms do the carbonates of copper occur?

[redacted]

tallizes in rhomboids of blue color, with four atoms of water. It is soluble in four times its weight of cold, and twice its weight of hot water. It is an escharotic, an astringent, and has an acid reaction. With ammonia it forms a compound of a splendid blue color, which may be obtained in crystals; with potash, also, it forms a double salt. There are also subsulphates of copper.

Nitrate of Copper, formed by the action of nitric acid on metallic copper. It crystallizes in prisms or in plates. It acts with very great energy on metallic tin. There is a subnitrate of copper.

Arsenite of Copper—Scheele's Green—produced by adding solution of arsenious acid to the solution of ammonia sulphate of copper.

Copper yields several valuable alloys. Brass is an alloy of copper and zinc; gun metal, bell metal, and speculum metal, of copper and tin. The gold and silver of currency contain portions of this metal; it communicates to them the requisite degree of hardness.

LECTURE LXVI.

LEAD.—*Reduction of Galena.—Relations of Lead to Water.—The Oxides of Lead.—Detection of Lead.—* BISMUTH.—SILVER.—*Amalgamation.—Crystallization.* ·· *Cupellation.—Properties of Silver.—Salts of Silver*

LEAD. $Pb = 103{\cdot}6$.

LEAD occurs under various mineral forms, but the most valuable one is galena, a sulphuret. From this it is readily obtained. The galena, by roasting in a reverberatory furnace, becomes partly converted into sulphate of lead; the contents of the furnace are then mixed, the temperature raised, and the sulphate and sulphuret produce sulphurous acid and metallic lead, the action being

$$PbO,\ So_3 + PbS \ldots = \ldots 2SO_2 + Pb_2.$$

Lead is a soft metal, of a bluish-white color. Its speci-

What are the method of preparation and properties of the sulphate? What is Scheele's green? What are brass, gun metal, and bell metal? Why is silver and gold coinage alloyed? Under what form does lead chiefly occur? How is galena reduced?

fic gravity is 11·381. It melts at 612° F., and on the surface of the molten mass an oxide (dross) rapidly forms. At common temperatures it soon tarnishes. In the act of solidifying it contracts, and hence is not fit for castings. It possesses, at common temperatures, the welding property; two bullets will cohere if fresh-cut surfaces upon them are brought in contact. Under the conjoint influence of air and water lead is corroded, a white crust of carbonate forming. But when there are contained in the water small quantities of salts, such as sulphates, these form with the lead insoluble bodies, which, coating its surface over, protect it from farther destruction. For this reason, lead pipe can be used for distributing water in cities without danger. Lead is one of the least tenacious of the metals. The tartrate of lead calcined in a tube yields one of the best pyrophori. On bringing it into the air at common temperatures, it spontaneously ignites.

Of the compounds of lead, the following are some of the more important:

Protoxide of lead	. . . . .	PbO	= 111·613.
Sesquioxide "	. . . . .	Pb_2O_3	= 231·239.
Peroxide "	. . . . .	PbO_2	= 119·626.
Red oxide "	. . . . .	Pb_3O_4	= 342·852.
Chloride "	. . . . .	$PbCl$	= 139·62.
Iodide "	. . . . .	PbI	= 229·9.
Sulphuret "	. . . . .	PbS	= 119·7.

The protoxide is made by heating lead in the air; it is a yellow body, which fuses at a bright red heat. In the first state it is called massicot; in the latter, litharge. It yields a class of salts, being a base. It is slightly soluble in water. The peroxide is made from red lead by digesting it with nitric acid, which dissolves out the protoxide, and leaves the substance as a puce colored powder. The red oxide, or red lead, is made by calcining lead in a current of air at 600° or 700° F. It is used in the manufacture of flint glass. The chloride is made by the action of hot hydrochloric acid on protoxide of lead: on cooling, it is deposited in crystals. The iodide is formed when any soluble iodide is added to protosalt of lead; it is a beautiful yellow precipitate, soluble in boiling water, forming a colorless solution, which, on cooling, deposits golden crystals.

Why can not lead be used for castings? What is the action of pure water, and water containing salts, upon it? What is massicot? How is it prepared? What is litharge? How is the peroxide prepared? How is minium made?

The sulphuret is galena; it crystallizes in cubes, and has a high metallic lustre.

Lead is easily detected by sulphureted hydrogen, which throws it from its solutions as a deep brown or black precipitate, and by the iodide of potassium or chromate of potash, which gives with it a yellow precipitate. Sulphuric acid yields with its salts a white insoluble sulphate of lead.

SALTS OF THE PROTOXIDE OF LEAD.

Carbonate of Lead—White Lead—Ceruse.—This salt forms as a white precipitate when an alkaline carbonate is added to a solution of a salt of lead. Large quantities of it are consumed in the arts as white paint. For commerce it is procured by mixing litharge with water containing a small proportion of acetate of lead; carbonic acid gas is then sent over it, and the carbonate rapidly forms. It is also made by exposing metallic lead in plates to the action of the vapor of vinegar, air, and moisture, the metal becoming oxydized and carbonated.

Nitrate of Lead may be formed by dissolving litharge in dilute nitric acid; it crystallizes in opaque white octahedrons, which dissolve in seven or eight times their weight of cold water. They contain no water of crystallization, and are decomposed at a red heat, as stated in the description of nitrous acid. By the action of ammonia, three other nitrates of lead may be obtained.

Among the alloys of lead are the soft solders. Two parts of lead and one of tin constitute plumber's solder; one of lead and two of tin, fine solder.

BISMUTH. $Bi = 71{\cdot}07$.

Bismuth is found both native and as a sulphuret. It is of a reddish color, melts at 497°, and may be obtained in beautiful cubic crystals by cooling a quantity of it until solidification commences, then breaking the surface crust and pouring out the fluid portion.

When bismuth is dissolved in nitric acid, and the solution poured into water, the white subnitrate is deposited, once used as a cosmetic; when this is washed, and subsequently heated, the protoxide is left. There is also a peroxide.

How may lead be detected? Mention some of the methods by which white lead may be made. What change does the nitrate undergo at a red heat? Of what are the common solders composed? What are the properties of bismuth?

Fusible metal is an alloy of eight parts of bismuth, five of lead, and three of tin; it melts below the boiling point of water, and may be obtained in crystals.

SILVER. $Ag = 108{\cdot}31$.

SILVER is found native, and as a sulphuret and a chloride, occurring, also, with a variety of other metals, and in small proportion with galena. When disseminated as a metal through ores, it may be collected from them by amalgamation with quicksilver, and, on distilling, the quicksilver is driven off.

When it is obtained from the sulphuret, that ore is roasted with common salt, which changes it into a chloride. This, with the impurities with which it may be associated, is put into barrels, which revolve on an axis, along with water, pieces of iron, and metallic mercury; the iron reduces the chloride to the metallic state, and the silver amalgamates with the mercury. This is washed from the impurities, strained through a bag to separate the excess of mercury, and the residue is driven off by distillation.

The extraction of silver, when it occurs in small quantity with lead, has been recently much improved by the introduction of the process of crystallization. It depends upon the fact that an alloy of lead and silver is more fusible than lead. A large quantity of argentiferous lead is melted and allowed to cool. As the setting goes on, the first portions which solidify are pure lead; they may be removed by iron colanders, and by continuing the process there is finally left a portion containing all the silver. This is exposed to a red heat, and a stream of air directed over it; oxydation of the lead takes place, and the litharge is removed by the blast, the process being finally completed by cupellation.

A cupel is a shallow dish made of bone ashes, and is very porous. In this, if an alloy of lead and silver be heated with access of air, the lead oxydizes, and, melting into a glass, soaks into the cupel, or may be driven from the surface by a blast of air directed from a bellows. At the same time, any copper or other base metal oxydizes and is removed along with the lead. The completion of the process is indicated by the silver assuming a certain brilliancy, or flashing, as the workmen term it.

What is fusible metal? Under what forms does silver commonly occur How is it reduced from the sulphuret? What is the process of amalgamation? What is the process of crystallization? What of cupellation?

Silver is a white metal capable of receiving a brilliant polish. It is malleable and ductile, an excellent conductor of heat and electricity. Its specific gravity is 10·5. It melts at 1873° F., and, when melted, absorbs a large quantity of oxygen, giving it out again as soon as it solidifies, and assuming a frosted or porous appearance. The presence of a minute quantity of copper prevents this effect. Silver is so soft that, for making plate or coins, it requires to be alloyed with a portion of copper; from this it may be purified by dissolving it in nitric acid. and precipitating the silver as chloride by a solution of common salt. Silver shows little disposition to unite with oxygen, though it tarnishes readily by the action of sulphureted hydrogen. It yields three oxides, but of its compounds the following are the most important:

Protoxide of silver	AgO	$= 116{\cdot}323.$
Chloride "	$AgCl$	$= 143{\cdot}78.$
Iodide "	AgI	$= 234{\cdot}48.$
Sulphuret "	AgS	$= 124{\cdot}43.$

The protoxide may be made by the action of caustic potash on a solution of nitrate of silver, or by boiling recently-prepared chloride in potash. It is a dark powder, which may be reduced by heat alone. The chloride is sometimes found native, as horn-silver, and may be made by precipitation from the nitrate by hydrochloric acid, or a soluble chloride. Like the iodide, it turns dark on exposure to the indigo rays, and hence is used in photogenic drawing. The sulphuret is produced whenever sulphureted hydrogen acts on oxide of silver, or even metallic silver; it is a black compound.

Silver is easily detected by precipitation as a chloride: a curdy, white precipitate, insoluble in water, but soluble in ammonia. It turns dark on exposure to the sun.

SALTS OF THE PROTOXIDE OF SILVER.

Nitrate of Silver—Lunar Caustic—procured by dissolving silver in nitric acid, diluted with twice its weight of water. It crystallizes in tables which are not deliquescent and contain no water of crystallization. It enters into fusion at 426° F., but at higher temperatures undergoes de-

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What are the properties of silver? Why does it frequently require to be alloyed with copper? What remarkable relation does it possess to oxygen? How may the protoxide be prepared? What changes do the chloride and iodide exhibit under the influence of light? How may silver be detected? How is lunar caustic made?

composition. It is frequently cast into small sticks and used by surgeons as a cautery. It is soluble in its own weight of cold and half its weight of hot water, and, when in contact with organic matter, turns black in the rays of the sun.

Ammoniuret of Silver—Berthollet's Fulminating Silver—is formed by digesting precipitated oxide of silver in ammonia. It explodes with the utmost violence under the feeblest friction, with the evolution of nitrogen and the vapor of water.

LECTURE LXVII.

MERCURY.—*Process of Reduction.—The Liquid State of.—Its Oxides.—Calomel and Corrosive Sublimate.—Detection of Mercury.—Its Salts.—Amalgams.*—GOLD—*Chloride of.—Purple of Cassius.*—PALLADIUM.—PLATINUM.—*Its Catalytic Effects.—Platinum Black.*—IRIDIUM.—RHODIUM.

MERCURY. $Hg = 202$.

MERCURY may be obtained from the bisulphuret (cinnabar) by distillation with iron filings. It is also, to a certain extent, found native.

The striking characteristic of mercury is its liquid condition. Its melting point is the lowest of that of any of the metals, being —39° F. Its specific gravity at 47° F. is 13·545. It boils at 662° F. Kept at that temperature in the air for a length of time, it produces red oxide, but at common temperatures it is not acted on by the air. It may be freed from impurities for the purposes of the laboratory by being kept in contact with dilute nitric acid. It gives the following compounds of interest:

Protoxide of mercury	HgO	= 210·013.
Peroxide "	HgO_2	= 218·026.
Protochloride "	$HgCl$	= 237·42.
Bichloride "	$HgCl_2$	= 272·84.
Protosulphuret "	HgS	= 218·1.
Bisulphuret "	HgS_2	= 234·2.

The protoxide may be made by triturating calomel with potash water in a mortar. It is a black powder, which is

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Under what forms does mercury commonly occur? What is the most striking property of this metal? How may it be purified? What are the properties of the protoxide of mercury?

decomposed by light or any of the reducing agents. The peroxide may be formed, as stated above, by the action of air on hot mercury, but more easily by dissolving mercury in nitric acid, and evaporating and heating the salt until no more fumes of nitrous acid are evolved. It is a red powder, and when warmed becomes almost black, the color returning as the temperature descends. Like the former, it is a base, and yields a class of salts.

The Protochloride, or *Calomel*, may be made by adding hydrochloric acid to the protonitrate of mercury, or by subliming a mixture of bichloride of mercury and mercury. It is a white powder, insoluble in water, and darkens slowly by exposure to sunshine. The *bichloride* (or *Corrosive Sublimate*) is formed when mercury burns in chlorine gas, but more economically by sublimation from a mixture of persulphate of mercury and common salt. It is a heavy, white crystalline body, soluble in water, has a metallic taste, and is poisonous. The antidote for it is albumen (the white of an egg).

Of the sulphurets of mercury, the protosulphuret is black, and the bisulphuret commonly red; in this case it passes in commerce under the name of vermilion, and is used as a paint. It can be obtained, however, quite black, a peculiarity already observed in the case of the peroxide, and still more strikingly in the biniodide, which may be sublimed in beautiful yellow crystals, which become of a splendid scarlet color by merely being touched.

Mercury may be detected by being precipitated from its soluble combinations by metallic copper as a metal. Its salts, either alone or with carbonate of soda, heated in a tube, yield metallic mercury, which volatilizes.

SALTS OF THE OXIDES OF MERCURY.

Nitrates of the Oxides of Mercury.—When cold dilute nitric acid acts on mercury, it gives rise to neutral or basic protosalts, as the acid or mercury is in excess; if the acid be hot, a pernitrate forms; these salts are decomposed by an excess of water, giving rise to basic compounds. The neutral pernitrate exists in solution only.

What are the properties of the peroxide of mercury? What is calomel? What is corrosive sublimate? What is the antidote to it? For what purpose is the bisulphuret employed? What change occurs to the yellow biniodide when it is touched? How may mercury be detected? How are the protonitrate and the persulphate prepared?

Persulphate of Mercury is formed by boiling sulphuric acid and mercury, and evaporating to dryness. It occurs in the form of a white granular mass, and is decomposed by water, giving a yellow precipitate, a subsulphate called *Turpeth Mineral.*

The alloys of mercury are called *amalgams ;* the amalgam of tin is used for silvering looking-glasses, and that of zinc for exciting electrical machines.

GOLD. $Au = 199{\cdot}2$.

Gold is found native, and may be obtained by washing or by amalgamation with mercury. It may be purified from silver by quartation ; that is, fusing it with three times its weight of silver, and then acting on the mass with nitric acid. The gold is left as a dark powder.

From all other metals gold is distinguished by its yellow color. Its specific gravity is 19·3. It melts at 2016° F. It is the most malleable of all the metals, as is proved by gold-leaf, which may be obtained $\frac{1}{200000}$ inch in thickness ; is not acted upon by the air or oxygen. Objects of art covered with it have retained their brilliancy for thousands of years. No acid alone dissolves it ; but it is soluble in aqua regia, and also by chlorine.

It can, however, be made to yield two oxides, a protoxide and a teroxide ; and two chlorides having the same constitution ; the terchloride is formed by the action of nitro-muriatic acid (aqua regia) on gold. When evaporated, it yields red, deliquescent crystals. Deoxydizing agents, such as protosulphate of iron, reduce it to the metallic state ; this is probably due to their decomposing water and presenting hydrogen to the chloride. Hydrogen gas decomposes the terchloride, and, by heating it, it first changes into the protochloride and then into metallic gold. With a solution of tin it forms the *Purple of Cassius.* This and the action of protosulphate of iron serve as a test for it.

PALLADIUM. $Pd = 53{\cdot}3$.

Palladium is found associated with platinum, and is best obtained from the cyanide of palladium by ignition. It is a white metal, requiring a high temperature for fusion ;

Under what forms does gold occur? What is quartation? What are the properties of this metal? How many oxides does it yield? How is the terchloride prepared? What is the purple of Cassius? With what metal is palladium generally associated? What are its properties?

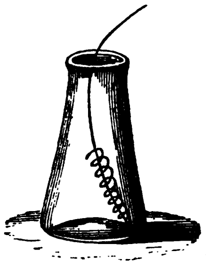
specific gravity 11·5. It does not tarnish in the air, is dissolved by nitric acid and aqua regia, is one of the welding metals, and, when heated, acquires a purple oxydation like watch spring. It is used to some extent by dentists. Its compounds are not of importance.

PLATINUM. $Pt = 98{\cdot}84$.

Platinum is found native, but always associated with other metals. It is obtained by first forming a chloride of platinum and ammonium; this, when ignited, leaves pure spongy platinum, which being exposed to powerful pressure, and then alternately made white hot and hammered, becomes a solid mass.

Platinum is a white metal. Its specific gravity is very high, being 21·5. It can not be melted in a furnace, but fuses before the oxyhydrogen blow-pipe. It is a welding metal, and on this fact its preparation depends. It is very malleable and ductile, is not acted upon by oxygen, air, or any acid alone, but dissolves in aqua regia. It possesses the extraordinary property of causing hydrogen and oxygen to unite at common temperatures, an effect which takes place with remarkable energy when the metal is in a spongy state. A jet of hydrogen falling upon spongy platina in the air makes it red hot, and presently after the gas takes fire. It also brings about the rapid transformation of alcohol into acetic acid, and various other chemical changes.

Fig. 274.



If a quantity of ether be poured into a glass jar, *Fig.* 274, and a coil of platinum wire, recently ignited, be introduced, the metal continues to glow so long as any ether is present.

Platinum is invaluable to the chemist. It furnishes a variety of implements of great value, and is met with under the forms of crucibles, tubes, wire, foil, &c.

Platinum Black is prepared by slowly heating to 212° a solution of chloride of platinum, to which an excess of carbonate of soda and

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What superficial effect takes place when it is heated in the air? How is platinum obtained from its ores? What is the specific gravity of this metal? By what acid may it be dissolved? What remarkable relations does it possess to hydrogen gas? Under its influence, what is alcohol transmuted into? What is platinum black?

some sugar have been added. It is a dark powder, and possesses the property of determining a variety of chemical changes with much more energy than platinum in mass.

Platinum can be caused to yield two oxides, which are not of any importance; and two analogous chlorides, of which the bichloride, which is the common platinum salt, is made by dissolving the metal in nitro-muriatic acid, and evaporating to a sirup. It is soluble in water and alcohol, and is used for detecting the salts of potash.

IRIDIUM. $Ir = 98{\cdot}84$.

Iridium is associated with platinum. It is said to have been found of specific gravity 26·00. Dr. Hare has obtained it 21·8; it is, therefore, the heaviest of the metals. Its name is derived from the different colors (iris) of its compounds.

RHODIUM. $R = 52{\cdot}2$.

Like the former metal, rhodium is associated with the platina ores. It is a hard white metal; its specific gravity is 11·00, and is sometimes used to form tips to metallic pens.

What are the properties of iridium? What are those of rhodium?

PART IV.

ORGANIC CHEMISTRY.

LECTURE LXVIII.

Peculiarities of Organic Bodies.—Their constituent Elements.—Prone to Decomposition.—Carbon always present.—Compound Radicals.—Doctrine of Substitution.—Types.—Action of Heat.—Eremacausis.—Propagation of Decay.—Action of Acids and Alkalies.

The theory of molecular arrangement, which has been already given, forms the foundation of organic chemistry. It asserts that the characters of compound bodies do not alone depend on the nature of their constituent elements, nor even on the relative amount of those elements; but that variation of physical forms may result from atoms of the same name and of the same number arranging themselves in subordinate groups, which groups then unite with each other.

The leading ultimate elements of organized bodies are carbon, hydrogen, nitrogen, and oxygen. Almost all organic bodies arise from variations in the number and grouping of identical elements.

Now a partial consideration of the conditions under which the theory of molecular arrangement acts, exhibits to us a most striking difference in the nature of the compounds formed upon its principles and the compounds heretofore described as examples of inorganic chemistry. In the one, peculiarity of grouping is the grand feature; in the other, the character of the combining elements. Urea differs from the cyanate of ammonia in the arrangement of its constituents only; but the leading mark of distinction between sulphuric and phosphoric acids is, that the one contains sulphur and the other phosphorus.

The number of substances which, besides the four men-

On what do the characters of compound bodies depend? Of what four leading elementary bodies are organic substances chiefly composed? In what striking respect do these substances differ from inorganic ones?

tioned above, enter into the composition of organic bodies is very limited. Among such may be mentioned potash, soda, lime, magnesia, oxide of iron, chlorine, fluorine, sulphur, phosphorus, and silica. Some of those bodies, such as alumina, which appear to take the lead in inorganic productions, are here scarcely seen.

While the laws of inorganic chemistry appear to be fully in operation as respects the bodies on the study of which we are now entering, there are some peculiarities which deserve to be pointed out. The remarkable instability, or proneness to decomposition, which so many of them exhibit, generally tends to the production of secondary compounds of a much more stable nature. At a red heat all organized bodies are decomposed; and as the elements of which they consist are endowed with the most energetic affinities, any extensive elevation of temperature tends to impress upon them a change. With but few exceptions, the attempts which have hitherto been made to produce them artificially have been abortive; but this is, probably, rather due to our want of knowledge than any intrinsic impossibility in effecting such combinations.

With the exception of a few bodies, such as ammonia, which, in point of fact, belong rather to inorganic chemistry, all organized bodies contain carbon. Of late, by indirect processes, chemists have succeeded in obtaining pseudo-organized compounds, into the constitution of which such bodies as platinum and arsenic enter.

In inorganic chemistry we see a constant disposition to the binary form of union: a disposition which is well represented by the electro-chemical theory. Thus, potassium unites with oxygen, two bodies together, to form potash; and this, again, with sulphuric acid, two bodies together, to form sulphate of potash. In very many instances, the same thing can be traced in organic chemistry; only here, instead of having such bodies as chlorine or iodine, potassium or sodium to deal with, we find compound bodies which discharge analogous functions. These bodies go under the name of compound radicals. They may be divided into distinct groups, some discharging the duty of electro-negative,

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What other elements are found among organic bodies? In their decomposition, what do they generally produce? Can any of them withstand a red heat? Can they be formed by artificial means? What is meant by compound radicals?

some of electro-positive, and some of indifferent bodies. In several cases they have been insulated, but in others they remain as yet as ideal or hypothetical bodies.

Table of Compound Radicals.

Amidogen.	Iridiocyanogen.	Acetyle.
Oxalyle.	Sulphocyanogen.	Kakodyle.
Cyanogen.	Mellone.	Methyle.
Ferrocyanogen.	Uryle.	Formyle.
Ferridcyanogen.	Benzyle.	Cetyle.
Cobaltocyanogen.	Salicyle.	Amyle.
Chromocyanogen.	Cinnamyle.	Glyceryle.
Platinocyanogen.	Ethyle.	

The qualities of bodies depending as much on the mode of arrangement of their constituent particles as on the chemical nature of those particles, it has been found convenient to arrange them in groups, according to their type of structure ; thus, for instance, in the former department of chemistry, such bodies as hydrochloric, hydriodic, hydrobromic acids may be arranged together as belonging to one type; and from the first of these all the rest may be conceived as arising, by substituting an atom of iodine, bromine, fluorine, &c., for the atom of chlorine which it contains.

The bodies which can thus be substituted for each other appear to have certain relationships ; for the substitution of a given substance can not take place indiscriminately by all other bodies. As a general rule, in inorganic combinations, electro-negative bodies can only be substituted by electro-negative, and electro-positive by electro-positive. But many of the most prominent cases in organic chemistry are precisely the reverse. In them, for example, we find chlorine, a powerful electro-negative, taking the place of hydrogen, an equally powerful electro-positive body, and, in the compound, discharging all its functions. For these reasons, it has been supposed that the electro-chemical theory fails to furnish any explanation ; but I have proved that chlorine, like many other bodies, can assume different allotropic states ; at one time being an active electro-negative body, and at another quite passive. Moreover, it ought not to be forgotten that hydrogen, in relation to carbon, is as much an electro-negative body as chlorine itself.

A chemical *type* is, therefore, a system, or group of atoms

What compound radicals are known? Under what circumstances can bodies be substituted for each other? Is there any difference in this respect between inorganic and organic bodies? What is a chemical type?

of a certain number, arranged in a certain relationship with each other. From this each atom may be displaced, and one of another kind *substituted* in its stead; and this may be carried forward until not one of the original atoms is left, the new group officiating in all respects like its predecessor. But should one of the atoms be displaced, and no new one substituted for it, then, the remaining atoms changing their position, the type is broken up and a new one is the result.

Organic compounds, being for the most part composed of carbon, hydrogen, nitrogen, and oxygen, exhibit a constant tendency to break up into subordinate groups, and eventually to give rise to the production of the simpler binary bodies, carbonic acid, water, and ammonia. The carbon constantly inclines to unite with oxygen to form carbonic acid, the hydrogen, in the same manner, to form water, or, with the nitrogen, to produce ammonia; and these tendencies may be satisfied in a variety of ways. Elevations of temperature in the open air at once give rise to carbonic acid, water, and free nitrogen; or if in close vessels out of the contact of air, to an extensive series of compounds, differing in each case with the substance exposed, and of a less complex constitution. Even in the air, at common temperatures, a slow action often goes on, as in the decay of wood or the souring of wine; hence called eremacausis (slow combustion).

When a combustible substance is ignited in the air at one point, the burning presently spreads throughout the whole mass; and in the slow combustion, eremacausis, the same takes place. A substance undergoing such a change, if placed in contact with another capable of undergoing it, propagates its effect throughout the whole mass. For this reason, the decay of yeast, a ferment, impresses a metamorphosis on sugar, compelling it to give off carbonic acid gas; and putrefaction of fresh meat is easily brought on by the contact of putrid animal matter.

Nitric, sulphuric, and other strong acids impress striking changes when heated with organic matters; thus, when the former acts on starch, oxalic acid is formed; when sulphuric

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Under what circumstances do new types result? What are the binary bodies eventually produced? What is the result of elevation of temperature in the open air? What in close vessels? What is meant by eremacausis? In what respect does eremacausis resemble common combustion? What is the effect of strong acids and alkalies on organic bodies?

acid acts on oxalic, it totally destroys it, resolving it into carbonic acid, carbonic oxide, and water. In the same manner, also, basic bodies produce striking changes, generally giving rise to the production of acids, and the evolution of hydrogen and ammonia.

In the present state of organic chemistry, it is impossible to present a perfect system of arrangement, as in inorganic chemistry, or one approaching to the finish of that department. The course, therefore, which I shall now take is recommended rather for its usefulness in facilitating study than for the propriety of its classification.

LECTURE LXIX.

THE NON-NITROGENIZED BODIES.—*The Starch Group.—Starch.—Action of Iodine.—Various Forms of Starch.—Production of Dextrine.—Action of Diastase.—Leiocome.—Cane Sugar.—Glucose.—Distinction between Cane and Grape Sugar.—Milk Sugar.—Gum.—Lignine.*

THE non-nitrogenized bodies, which we shall first consider, are characterized by the peculiarity that they form a group, each member containing twelve atoms of carbon, united with hydrogen and oxygen in the proportions to form water. They are, for the most part, indifferent bodies.

The Starch Group.

Starch	$C_{12}H_{10}O_{10}$.
Cane sugar (crystallized)	$C_{12}H_{11}O_{11}$.
Grape sugar	$C_{12}H_{14}O_{14}$.
Milk sugar	$C_{12}H_{12}O_{12}$.
Gum	$C_{12}H_{11}O_{11}$.
Lignine	$C_{12}H_{8}O_{8}$.
&c.	&c.

Starch—Fecula ($C_{12}H_{10}O_{10}$)—is found abundantly in the vegetable kingdom, and may be obtained from potatoes by rasping and washing the mass upon a sieve, the starch being carried off by the water. It may also be obtained from flour by making it into a paste with water and then washing it. The starch separates, and gluten is left behind.

How many carbon atoms does each member of the amyle group contain In what proportion are their oxygen and hydrogen? Mention some of the chief bodies of this group. From what sources, and in what manner, is starch obtained?

It is a white substance, commonly met with in irregular prismatic masses, which shape it assumes while drying. It is insoluble in cold water, and also in alcohol, and consists of granules of different sizes, as it is derived from different plants, those of the potato being about the two hundred and fiftieth of an inch in diameter.

When starch is heated in water, the covering membrane of each granule bursts open, and the interior matter dissolves out. If the proportion of starch be considerable, the whole forms a jelly-like mass, which may be dried in a yellowish body, having the same constitution as starch itself. Gelatinous starch passes under the name of *Amidine*.

With free iodine, starch strikes a deep blue color. When water containing this compound is heated to 212° F., the color totally disappears, and is not restored on cooling; but if the source of heat be removed as soon as the color disappears, and before the temperature reaches 212° F., the color returns. Starch and iodine constitute an exceedingly delicate test for each other.

In commerce, starch is found under various modifications, such as *Arrow-root*, *Tapioca*, *Cassava*, *Sago*. It forms an important article of respiratory food. *Inuline*, which is derived from the dahlia and other plants, is a substance approaching starch in many respects.

When starch is boiled in water with a small quantity of sulphuric acid, it changes into *Dextrine*, a substance of the same composition; the acid being subsequently removed by carbonate of lime and filtration, that body is procured on evaporation as a gummy mass. But if the ebullition be continued for a longer time, the dextrine disappears, and grape sugar comes in its stead. Starch may also be converted into grape sugar by the action of a peculiar ferment, *Diastase*, which is contained in an infusion of malt. Gelatinous starch may, in the course of a few minutes, at 160° F., be converted into dextrine by this substance, and soon after into sugar. In either of these cases the presence of atmospheric air is not required; the final action being that the starch simply assumes three atoms of water, and becomes converted into grape sugar.

What is the size of its granules? What is the effect of hot water on it? What is a amidine? What is the action of iodine on starch? Mention some other varieties of starch. How is it converted into dextrine? How into grape sugar? What is diastase? What is its action on starch?

When baked at a temperature of about 400° F., starch becomes soluble in water, and passes in commerce under the name of *British Gum*, or *Leiocome*.

Cane Sugar ($C_{12}H_9O_9 + 2HO$) is found abundantly in the juices of many plants, and is chiefly extracted for commercial purposes from the sugar-cane, which, being crushed between rollers, yields a juice, which is mixed with lime and boiled; a coagulum having been removed from it, it is rapidly evaporated, at as low a temperature as possible, and then crystallized. In this state, after a brownish sirup, molasses, has drained from it, it passes in commerce under the name of *Muscovado*, or brown sugar. This is purified by boiling in water with albumen, which, coagulating, separates many of the impurities; the solution is then decolorized by animal charcoal, evaporated, solidified in conical vessels, and, being washed with a little clean sirup, is thrown into commerce as loaf-sugar. Sugar is also obtained from the sap of the maple-tree, and from beet-root.

From a strong solution sugar crystallizes in rhombic prisms, which are colorless; they pass under the name of *Sugar Candy*. It is soluble in one third its weight of cold water, and in any quantity of hot. It has a sweet and proverbially characteristic taste. When heated, it melts, and gives rise to a yellowish, transparent body, called *Barley Sugar*. But if kept at a temperature of 630° F., it turns of a reddish-brown color, constituting *Caramel*. Sugar unites with various bodies, such as lime and oxide of lead, and with common salt yields a crystallized product. By caseine it is transformed into lactic acid.

Grape Sugar—Fruit Sugar—Glucose—Starch Sugar—Diabetic Sugar ($C_{12}H_{14}O_{14}$)—is the substance just described as arising from the transmutation of starch under the influence of acids. It occurs naturally in many vegetable juices and in honey.

Compared with cane sugar, it is much less soluble in water, and less disposed to crystallize. It requires 1½ parts of water for solution. It may be distinguished by its action with caustic alkalies and sulphuric acid, the former turning it brown, and the latter dissolving it without blacken-

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How is British gum formed? From what sources, and by what means, is cane sugar derived? What are its properties? By what means is caramel formed? What is the difference between cane and grape sugar? By what test may they be distinguished?

ing, while cane sugar is little acted on in the former instance, and blackened in the latter. The two varieties may also be distinguished by being mixed with a solution of sulphate of copper, to which, if caustic potash be added, blue liquids are obtained, and these being heated, the grape sugar throws down a green precipitate, which turns deep red, the solution being left colorless : the cane sugar alters very slowly, a red precipitate gradually forming, and the liquid remaining blue. Grape sugar, like cane sugar, gives with common salt a crystallized compound. When heated to 212° F. it loses two atoms of water, and becomes $C_{12}H_{12}O_{12}$.

Milk Sugar—Lactine ($C_{12}H_{12}O_{12}$)—may be obtained by evaporating whey to a sirup, and the crystals which then form are to be purified by animal charcoal. It is sparingly soluble, requiring five or six times its weight of water. The crystals are gritty between the teeth. It is through the alcoholic fermentation of this body that the Tartars procure intoxicating milk.

Besides the foregoing, there are several subordinate varieties of sugar, among which may be cited

Ergot sugar	$C_{12}H_{13}O_{13}$;
Eucalyptus sugar	$C_{12}H_{14}O_{14}$;

and others, as liquorice sugar, mushroom sugar, or mannite, &c.

GUM.—*Gum Arabic* is obtained from several species of the mimosa or acacia, from the bark of which it exudes; is obtained in white or yellowish tears, of a vitreous aspect. It dissolves in cold water, forming *mucilage*, from which it may be precipitated pure, as *Arabine*, by alcohol.

Bassorine is the principle of *Gum Tragacanth;* it does not dissolve in water, but merely forms a jelly-like mass. With this substance should be classed *Pectine*, the jelly obtained from currants and other fruits. This substance furnishes *Pectic* acid by the action of bases.

LIGNINE.—This substance, with *Cellulose* and other bodies, forms the woody fibre or ligneous tissue of plants. It occurs in a state of purity in the fibres of fine linen and cotton, and, as is well known, is of perfect whiteness, insoluble in water and alcohol, and tasteless. Strong and cold

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What are the properties of milk sugar? Mention some other varieties of sugar? From what source is gum derived? What are arabine, bassorine, and pectine? How may lignine be prepared? When pure, what is its [illegible] and what is its relation to water?

sulphuric acid converts it into a dextrine, as may be shown by adding to that substance pieces of linen, taking care that the temperature does not rise so as to blacken the mixture, which is to be well stirred, and suffered to stand for a time. On dissolving it then in water, and neutralizing by the addition of chalk, dextrine is obtained; or if, before neutralizing, the solution is well boiled, grape sugar is produced

LECTURE LXX.

ACTION OF AGENTS ON THE STARCH GROUP.—*Action of Sulphuric Acid on Sugar.—Glucic Acid produced by Lime.—Melassic Acid.—Action of Nitric Acid.—Production of Oxalic Acid.—Constitution of Oxalic Acid.—Its Salts.—Oxamide.—Saccharic Acid.—Rhodizonic and Croconic Acids.—Mucic Acid.—Xyloidine.—Its Properties.*

IN the preceding Lecture we have already explained the change of starch into sugar, and of lignine into dextrine, under the influence of sulphuric acid; and in the vegetable world there can be no doubt that these and other similar modifications arise from the action of many causes. On inspecting the constitution of the group, it will be seen that, in theory, this is to be done by the addition or abstraction of water.

When melted grape sugar is mixed with strong sulphuric acid, and the diluted solution neutralized with carbonate of baryta, the sulphosaccharate of baryta is found in the solution. The *Sulphosaccharic* acid is a sweetish liquid, readily decomposing into sugar and sulphuric acid.

When, in the process of converting cane sugar into grape sugar by boiling with sulphuric acid, the action is long continued, a dark-colored substance is formed, consisting of two different bodies, *Ulmine* and *Ulmic Acid*, or, as they are termed by Liebig, *Sacchulmine* and *Sacchulmic Acid*. The latter is converted into the former by continual boiling in water.

When a solution of grape sugar containing lime is kept

How may lignine be converted into dextrine and grape sugar? In this change, what is the action impressed on the lignine? How is sulphosaccharic acid made? What are sacchulmine and sacchulmic acid?

for some time, the alkaline reaction of the lime finally disappears through the formation of *Glucic Acid*, the constitution of which is $C_8H_5O_5$. It is soluble, deliquescent, of a sour taste, and yielding, for the most part, soluble salts. If grape sugar be boiled with potash water until it becomes black, a dark substance may be precipitated by an acid. This is *Melasinic Acid*, its constitution being $C_{12}H_6O_5$.

These are some of the less important results of the action of acid and alkaline bodies on the starch group; there are others of far more interest.

OXALIC ACID (C_2O_3, $HO + 2Aq$).—Oxalic acid is formed by the action of nitric acid on starch or sugar, or any other of the starch group, except gum and sugar of milk One part of sugar is to be mixed with five of nitric acid, diluted with twice its weight of water, and the acid finally distilled off until the residue will deposit crystals on cooling. These, being collected, are to be purified by redissolving and crystallizing. They are oblique rhombic prisms, more soluble in hot than cold water, of an intensely acid taste, and poisonous to the animal economy, chalk or magnesia being the antidote. Oxalic acid also occurs naturally in several plants, in union with potash or lime.

As the foregoing formula shows, the crystals of oxalic acid contain one equivalent of saline water and two of water of crystallization. The latter may be removed by exposure to a low heat, the crystals then becoming a white powder, and subliming without difficulty. Any attempt to remove the saline water and isolate the oxalic acid (as C_2O_3) leads to its decomposition. Thus, when the acid is heated with oil of vitriol, total decomposition results; equal volumes of carbonic oxide and carbonic acid are set free; for the constitution of oxalic acid is such, that we may regard it as composed of an atom of each of these bodies:

$$C_2O_3 \ldots = \ldots CO_2 + CO;$$

and upon this is founded one of the methods of preparing carbonic oxide gas. The gaseous mixture which results from the action of the oil of vitriol is passed, as in *Fig.* 250, through a bottle containing potash water, which absorbs the carbonic acid, and the carbonic oxide may be collected at the water trough.

What is the constitution of glucic acid? What is the action of potash on grape sugar? Describe the preparation of oxalic acid. What is the antidote to it? What is the action of oil of vitriol on oxalic acid?

The production of oxalic acid from sugar by nitric acid is due to the replacement of hydrogen by an equivalent quantity of oxygen.

$$C_{12}H_9O_9 \,..+ O_{18} \,...=...\, C_{12}O_{18} \,..+ H_9O_9\,;$$

that is, one atom of dry sugar with eighteen of oxygen yields six atoms of oxalic acid and nine of water.

Salts of Oxalic Acid.

There are three potash salts : 1st. *Neutral Oxalate of Potash,* made by neutralizing oxalic acid with carbonate of potash ; crystallizes in rhombic prisms, soluble in three times its weight of water. 2d. *Binoxalate of Potash,* made by dividing a solution of oxalic acid into two parts ; neutralize one with carbonate of potash, and then add the other. It crystallizes in rhombic prisms, has a sour taste, and dissolves in forty parts of water. It occurs naturally in several plants, as the *Oxalis Acetosella.* 3d. *Quadroxalate of Potash.* Divide a solution of oxalic acid into four parts ; neutralize one, and add the rest. It crystallizes in octahedrons ; is less soluble than either of the foregoing These salts are sometimes used for the removal of ink stains from linen.

Oxalate of Ammonia, prepared by neutralizing a hot solution of oxalic acid with carbonate of ammonia. It crystallizes in rhombic prisms, which are efflorescent. Its solution is used, as has been already stated, as a test and precipitant of lime. When exposed to heat in a retort, is is, for the most part, decomposed into water, ammonia, carbonic acid, cyanogen, and other compounds ; but a substance of the name of *Oxamide* also sublimes, the constitution of which is

$$C_2H_2\,NO_2 ...=...\, NH_2 + 2(CO),$$

that is, containing the constituents of one atom of amidogen and two of carbonic oxide. This remarkable substance, when boiled with potash, yields, through the decomposition of water, oxalate of potash and ammoniacal gas.

Oxalate of Lime occurs naturally, forming the skeleton of many lichens, and is obtained, as has just been said, by precipitating a lime salt. It is soluble in nitric acid, and,

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How is oxalic acid produced from sugar? How many oxalates of potash are there? How are they prepared? For what purpose are these salts sometimes used? Under what circumstances does oxamide form? What is its constitution?

ignited in a covered crucible, is converted into carbonate of lime.

Saccharic Acid ($C_{12}H_5O_{11} + 5HO$)—*Oxalhydric Acid* —made by the action of dilute nitric acid on sugar. It is a pentabasic acid.

Rhodizonic Acid ($C_7O_7 + 3HO$), obtained by the action of potassium on carbonic oxide at a red heat. When boiled, it changes into *Croconic Acid*, a yellow body having the constitution $C_5O_4 + HO$.

Mucic Acid ($C_{12}H_8O_4 + 2HO$), obtained by the action of dilute nitric acid on gum or sugar of milk, as in the preparation of oxalic acid by other members of the starch group. It requires sixty times its weight of water for solution. Decomposed by heat, it yields pyromucic acid.

Xyloidine ($C_6H_4O_4, NO_5$), made by the action of nitric acid, sp. gr. 1·5, on the starch, which is converted into a gelatinous body, and yields this substance as a white precipitate when acted on by water. Its origin is apparent from a comparison of its formula with that of starch. Xyloidine is insoluble in boiling water, but by the continued action of nitric acid changes into oxalic acid. 100 parts of starch yield 128 of xyloidine.

Gun Cotton.—*Pyroxyline.* A remarkable compound, proposed as a substitute for gunpowder by Schonbein, whose process for preparing it has not yet been divulged. It may be made by the action of monohydrated nitric acid on cotton, paper, or sawdust; and still more conveniently by a mixture of nitric and sulphuric acids on those substances.

The cheapest and best process for its preparation is that discovered by Professor Ellet, of South Carolina College It consists in soaking carded cotton for a few minutes in a mixture of pulverized nitrate of potash and oil of vitriol, washing the result in hot water to free the cotton from the potash salt, and finishing the washing by a weak solution of ammonia. Gun cotton appears white, like ordinary cotton, the fibre being little changed; it is somewhat harsh to the touch; when perfectly dry, it explodes when heated to about 300° F., or by the blow of a hammer. It is esti-

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How is saccharic acid made? How is the rhodizonate of potash formed? What is its composition? How is it changed into croconic acid? Under what circumstances does mucic acid form? Decomposed by heat, what does mucic acid yield? How is xyloidine prepared, and what are its properties?

mated as having about three times the mechanical force of gunpowder. 100 parts of cotton yield about 165 of gun cotton. It contains twice as much nitric acid as xyloidine.

LECTURE LXXI.

ON THE METAMORPHOSIS OF THE STARCH GROUP BY NITROGENIZED FERMENTS.—*Action of Leaven.—Bread.—Fermentation of Sugar.—Fermentation of Grape Juice.—Primary Action on the Ferment.—Activity of Ferments due to Nitrogen.—Effects of Temperature.—Production of Butyric Acid.—Ferments of different Properties.—Production of Wine and intoxicating Liquids*

IN the preceding Lecture we have traced the action of the more powerful inorganic agents on the amyles, and seen how a variety of bodies of different characters arise, some of which, as oxalic acid, are of very considerable importance

But there is another system of changes which can be impressed on this group of bodies, far more curious in its nature, and leading to far more important results.

When flour, made into a paste with water, is brought in contact with *Leaven*, that is to say, a similar dough, undergoing an incipient putrefactive fermentation, at a temperature of 60° or 70° F., bubbles of gas are disengaged, the paste swells up, and, when baked, forms leavened bread. This ancient process, which is now in use all over the world, depends on the action of the changing leaven being propagated to the sugar which the flour contains. The sugar is resolved into alcohol and carbonic acid gas, the former of which may be obtained by distilling the dough; and the bubbles of the latter, entrapped in the yielding mass, gives to the bread the lightness for which it is prized.

But this process may be better traced by observing the phenomena of alcoholic fermentation in the case of pure sugar. If we take a solution of sugar in water, it may be kept for a length of time without undergoing any change; but if nitrogenized matters, such as blood, albumen, leaven, in a state of putrescent decay, are mixed with it, then, at a

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What is the action of leaven on flour? What is the action of decaying nitrogenized matter on a solution of sugar?

temperature of 70° F., the sugar rapidly disappears, carbonic acid is given off, and alcohol is found in the solution. The change is obvious.

$$C_{12}H_{12}O_{12} \ldots = \ldots 2(C_4H_6O_2) + 4(CO_2);$$

that is, one atom of dry grape sugar yields two of alcohol and four of carbonic acid. The final action, therefore, of the ferment is to split the sugar atom into carbonic acid and alcohol.

Of all ferments, *Yeast*, for these purposes, is the most powerful; it is a substance which arises during the fermentation of beer. It is probable that, in the various sugars, the first action is to bring them into the condition of grape sugar, and then the metamorphosis ensues.

By an analogous transformation of the sugar contained in fruits, the different wines and other intoxicating liquids are formed; thus, if we take the expressed juice of grapes which has not been exposed to the contact of air, it may be kept for a length of time without change; but if a single bubble of oxygen is admitted to it, fermentation at once sets in, the grape sugar disappears, and alcohol comes in its stead, carbonic acid gas being disengaged, and the nitrogenized substance, yeast, deposited. If a solution of pure sugar be added, it is involved in the change, and portion after portion will disappear; but, finally, the yeast itself is exhausted, and then any excess of sugar remains unacted upon.

It is obvious that the primary action is an oxydation of the ferment, and the moment its particles are set in motion, the motion is propagated to the adjacent body, the particles of which submit in succession; and therefore the fermentation is not a sudden action, but one requiring time. Moreover, it is plain that the action is limited; a given quantity of yeast will transmute only a definite quantity of sugar.

The ferments, or bodies which possess this singular quality, are nitrogenized bodies; and, inasmuch as non-nitrogenized bodies never spontaneously ferment while oxydizing, it is to the nitrogen that we are to impute the qualities in question.

Temperature has a remarkable control over ferment action. The juice of carrots or beets, fermenting at 50°

Into what bodies does the sugar atom split? What is the action of yeast on sugar? Describe the action of yeast on grape juice. What is the primary action in these cases? Is the action of the ferment definite? To what element in the yeast is the action due? What is the effect of temperature on fermentation?

Fahr., will yield alcohol, carbonic acid, and yeast; but the same juices, fermenting at 120° Fahr., produce lactic acid, gum, and mannite. Under these circumstances, therefore, alcohol is the product of fermentation at low, and lactic acid at high temperatures.

But when milk ferments at 50° Fahr., lactic acid is the chief product, while at 80° Fahr. the casein acts like a yeast ferment, the milk sugar becoming transformed into grape sugar, and then resolving itself into alcohol and carbonic acid. In this instance the action is the reverse of the former, lactic acid being the product of a low, and alcohol of a high temperature.

A very remarkable decomposition takes place when casein ferment acts on sugar at 80° Fahr. in presence of carbonate of lime. Under these circumstances, carbonic acid gas and hydrogen are evolved, and *Butyric Acid* appears. On comparing the constitution of butyric acid with alcohol, it will be seen that the latter contains the elements of the former, with an excess of hydrogen; so that, during this fermentation, the alcohol atom is divided.

All ferments possess certain properties in common, but each has its specific powers; and the products which are evolved differ in different cases. Most commonly the activity of these bodies is excited by an incipient oxydation, the result of which would be to bring the ferment itself to a simpler constitution. In this respect, therefore, the first stage of fermentation is a combustion at common temperatures, or an eremacausis of the ferment itself; but this action is speedily propagated to the surrounding mass, which becomes involved in the change. Whatever, therefore, prevents the incipient oxydation of the ferment, puts a stop to the whole process. By raising their temperature to 212°, and then cutting off the access of air, substances which would otherwise undergo a very rapid change may be kept for any length of time without alteration. On this principle, meats, milk, and other viands may be preserved.

We have now pointed out the peculiarities of ferment action, showing that two successive stages may be traced in the process; the first arising in the oxydation of the fer-

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Describe the causes of the fermentation of vegetable juices and of milk? Under what circumstances does butyric acid form? What is the change which the ferment itself undergoes? What is the effect of cutting off the access of air? What are the two stages of ferment action?

ment, by which its molecules are decomposed; and the second, which consists in the propagation of this movement to the surrounding particles, upon which changes are impressed, the nature of which differs with the temperature and the specific action of the ferment itself.

Wine is made from the expressed juice of grapes, which containing a nitrogenized body, albumen, when exposed to the air undergoes spontaneous fermentation; the course of the action being, 1st. The oxydation of the vegetable albumen; 2d. The propagation of its action to the grape sugar. If the sugar is in excess, the wine remains sweet; if the albumen is in excess, the wine is dry. The wine, as soon as the first action is over, is removed into casks. During these changes, the bitartrate of potash, which exists naturally in grape juice, and which, though sparingly soluble in water, is much less so in alcohol, is deposited. It goes under the name of *Argol.* Most other fruit juices contain free acid, such as malic or citric; and hence good wine can not be made from them, because, if all the sugar is removed, they possess a sharp taste; and if, as is commonly the case, a portion is left to correct the acidity, it is liable to run into a second fermentation.

Inferior liquids, such as cider, perry, &c., are made from other vegetable juices, as those of apples, pears, &c. Beer, porter, and ale are made from an infusion of malt, which is barley, a portion of the starch of which is transposed into sugar by partial germination. The principles of the fermentation are, in all these instances, the same.

LECTURE LXXII.

ON THE DERIVATIVES OF FERMENTATIVE PROCESSES.—*Alcohol.—Its Properties.—Exists in Wines.—Lactic Acid.—Production and Properties.—Sulphuric Ether.—Its Distillation.—The Ethyle Series.—Chloride.—Bromide.—Nitrate, &c.—Œnanthic Ether.*

ALCOHOL (*Hydrated Oxide of Ethyle*) $C_4H_6O_2$.

BY the distillation of wine, or any other fermented sac-

What is the process for the making of wine? When is the wine sweet and when dry? What is argol? Why are other fruit juices less proper for making wine than grape juice? How is alcohol procured?

charine juice, spirits of wine may be obtained. As first prepared, it contains a large quantity of water, which comes over with it. This product being rectified, and the first portion preserved, yields a spirit containing twelve to fifteen per cent. of water. By putting this into a retort with half its weight of quicklime, keeping the mixture a few days, and then distilling at a low temperature, absolute or anhydrous alcohol is obtained.

Anhydrous alcohol is a colorless liquid, of a burning taste and pleasant odor. Its specific gravity, at 60° F., is 0·795. It boils at 173° F., and at a still lower point if slightly diluted with water, though the boiling point rises if the water be in greater proportion. It has not been yet frozen. The specific gravity, also, varies with the amount of water present; and hence the purity of spirits of wine may be determined by ascertaining its density. Alcohol is very inflammable, burns with a pale blue flame, with the production of carbonic acid gas and water. It is much used in chemical investigations as furnishing a lamp flame free from smoke, and as possessing an extensive range of solvent powers, acting upon resins, oils, and other bodies, which are not acted upon by water.

The strong wines, such as port and sherry, contain from nineteen to twenty-five per cent. of alcohol; the light wines from twelve per cent. upward; and beer, porter, &c., from five to ten per cent.

Lactic Acid Fermentation.—We have already seen that vegetable juices as well as milk will, under certain circumstances of temperature, yield, during fermentation, lactic acid instead of alcohol. This acid may therefore be made by dissolving a quantity of sugar of milk in milk, putting it in a warm place, and allowing it to turn sour spontaneously. A part of the casein of the milk here acts as the ferment, and as lactic acid is set free, it coagulates the rest and makes it insoluble. By the addition of carbonate of soda, to neutralize the acid, this is prevented, and the ferment, resuming its activity, produces more lactic acid. When, by this process, all the sugar is exhausted, the liquid is boiled, filtered, evaporated to dryness, and the lactate of

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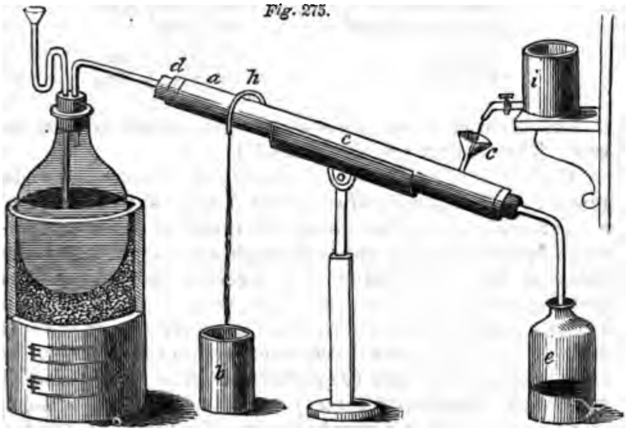
How may it be obtained anhydrous? What are its properties? How may the strength of spirits of wine be determined? For what purposes is it used in chemistry? How much alcoho per cent. is contained in port, sherry, beer, and ale?

soda dissolved out by hot alcohol. From this alcoholic solution the acid may be obtained by precipitating the soda by sulphuric acid.

Lactic Acid ($C_6H_5O_5+HO$) is obtained as a sirupy solution by concentrating in a vacuum over oil of vitriol. It is colorless, has a specific gravity of 1·215, is very sour, and soluble in water and alcohol. It yields a complete series of salts, most of which are soluble. Among these salts, the most interesting are those of lime and of zinc.

ETHER—*Sulphuric Ether—Oxide of Ethyle* (C_4H_5O).—Ether is prepared by distilling equal weights of alcohol and oil of vitriol, receiving the resulting vapor in a Liebig's condenser, *a d h c*, as in *Fig.* 275, the condenser being cooled by water from the reservoir, *i*, flowing into the funnel, *c*, the waste passing into the vessel, *b*, and the ether distilling into the bottle, *e*. The process is to be stopped as soon as the mixture begins to blacken. The first product may be rectified by redistillation from caustic potash.

Fig. 275.



Ether is a colorless and limpid liquid, of a peculiar odor and hot taste. It boils at 96° F., and has not yet been frozen. Its specific gravity, at 60° F., is ·720. It volatilizes with rapidity, and therefore produces cold. It is com-

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What is the process for obtaining lactic acid? What is its constitution? What are its properties? How is ether made? What are the properties of ether?

bustible, and burns with the evolution of much more light than alcohol. The specific gravity of its vapor is 2·586. With oxygen or atmospheric air it forms an explosive mixture, and, kept in contact with air, it becomes acid from the production of acetic acid. It dissolves in alcohol in all proportions, but ten parts of water are required to dissolve one of it; it also dissolves many fatty substances, and hence is of considerable use in organic chemistry.

Ether is regarded as the oxide of an ideal compound radical, ethyle, C_4H_5, which gives rise to a series of other bodies.

The Ethyle Group.

Ethyle, C_4H_5 . . . . = $Ae.$
Oxide of ethyle . . . . . = $Ae, O.$
Hydrated oxide . . . . . = $Ae, O + HO.$
Chloride of ethyle . . . . = $Ae, Cl.$
Bromide " . . . . = $Ae, B.$
Nitrate " . . . . = $Ae, O + NO_5.$
Hyponitrite " . . . . = $Ae, O + NO_3.$
&c. &c.

The oxide of ethyle, as has just been stated, is ether itself. The hydrated oxide is alcohol.

Chloride of Ethyle—Hydrochloric Ether—may be made by saturating rectified spirits of wine with dry hydrochloric acid gas, and distilling the result at a low temperature, conducting the vapor through a bottle of warm water, and then condensing in a receiver surrounded by a freezing mixture. It is a colorless, volatile liquid, of a peculiar aromatic smell; the specific gravity is ·874. It boils at 52°, and is not decomposed by nitrate of silver.

Bromide of Ethyle (*Hydrobromic Ether*) and *Iodide of Ethyle* (*Hydriodic Ether*) are not of any importance; and the same remark may be made as respects the *sulphuret* and the *cyanide.*

Nitrate of Ethyle—Nitric Ether—may be made on the small scale by distilling equal weights of alcohol and nitric acid with a small quantity of nitrate of urea. The latter substance is used to prevent the nitric acid deoxydizing, and giving rise to the production of hyponitrite instead of nitrate of ethyle. Nitrate of ethyle is insoluble in water, has a density of 1·112, boils at 185°, and has a sweet taste. Its vapor explodes when heated.

Is ether soluble in water? What class of bodies does it dissolve? Of what substance is it an oxide? What is the true name of hydrochloric ether, and how is it prepared? How is the nitrate of ethyle made?

Hyponitrite of Ethyle—Nitrous Ether (AeO, NO_3).—This ether may be made by passing the hyponitrous acid, disengaged from one part of starch and ten of nitric acid, through alcohol, diluted with half its weight of water and kept cold. It is a yellowish, aromatic liquid, having the odor of apples. It boils at 62° F. Its density is ·967. The sweet spirits of nitre is a solution of this ether with aldehyde and other substances in alcohol.

Carbonate of Ethyle—Carbonic Ether (AeO, CO_2).—made by the action of potassium on oxalic ether, and distillation of the product with water. It floats on the surface of the distilled liquid, is an aromatic liquid, and boils at 259°.

Oxalate of Ethyle—Oxalic Ether—prepared by distilling four parts of binoxalate of potash, five of sulphuric acid, and four of alcohol into a warm receiver. The product is washed with water to separate any alcohol or acid, and redistilled. It is an oily liquid, of an aromatic odor; it boils at 353° F., and is slightly heavier than water. With an excess of ammonia it yields *Oxamide* and alcohol. With a smaller proportion of ammonia and alcohol it yields *Oxamethane*, $C_8H_7NO_6$.

Acetate of Ethyle—Acetic Ether ($AeO, C_4H_3O_3$)—and *Formiate of Ethyle—Formic Ether* (AeO, C_2HO_3)—are procured in a similar manner with the foregoing, substituting in one case acetate of potash, and in the other formiate of soda.

Œnanthic Ether ($AeO, C_{14}H_{13}O_2$) is prepared from an oily liquid which passes over during the distillation of certain wines. It has a powerful vinous odor, is a colorless liquid, specific gravity ·862; it boils at 410° F., dissolves readily in alcohol, and gives their peculiar aroma to the wines in which it is found. From it œnanthic acid may be obtained by the successive action of potash and sulphuric acid. It is an oily body, becoming a soft solid at 55° F.

How is nitrous ether prepared, and what are its properties? How are carbonic ether, acetic ether, and formic ether made? From what source is œnanthic ether derived? What is its relation to various bodies?

LECTURE LXXIII.

DERIVATIVE BODIES OF ALCOHOL.—*Sulphovinic and Phosphovinic Acids.—Products of Sulphovinic Acid at different Boiling Points.—The continuous Ether Process—The continuous Olefiant Gas Process.—Dutch Liquid.—Successive Substitutions of Chlorine in it.—Heavy and Light Oil of Wine.—Sulphate of Carbyle and its derivative Acids.*

SULPHOVINIC *Acid—Bisulphate of Ethyle* ($C_4H_5O.2SO_3+HO$).—A mixture of sulphuric acid with an equal weight of alcohol is to be heated to the boiling point, and then allowed to cool. It is then to be diluted with water and neutralized with carbonate of baryta; the sulphate of baryta subsides. The solution is then filtered, evaporated, and, when cold, the sulphovinate of baryta crystallizes. From this the sulphovinic acid may be obtained by precipitating the baryta with dilute sulphuric acid, and evaporating the resulting solution in vacuo. It is a sirupy liquid, of a sour taste, giving rise to a series of soluble salts, which decompose at the boiling point, as will be presently seen.

Phosphovinic Acid (C_4H_5O, PO_5+2HO) is made on the same principles as the foregoing, phosphoric acid being substituted for sulphuric, and decomposing the resulting baryta salt in the same way. It is a sirupy liquid, of a sour taste, and dissolves in water, alcohol, and ether very readily It is decomposed by heat.

If sulphovinic acid be diluted so as to bring its boiling point below 260° F., it is resolved at that temperature chiefly into sulphuric acid and alcohol, which distills over.

If the boiling point is from 260° F. to 310° F., the distillation results chiefly in the production of hdyrated sulphuric acid and ether.

If, by the addition of sulphuric acid, the boiling point is carried above 320° F., the action is more complex, but the chief product which passes over is olefiant gas.

How is sulphovinic acid made? What is its composition? What is th composition and mode of preparation of phosphovinic acid? What is the esult of the exposure of sulphovinic acid at different boiling points?

The ordinary method of preparing ether is, therefore, obviously very disadvantageous, because it is only within a particular range of temperature that that body is evolved. At first the low temperature yields alcohol, and as the heat rises, the mixture begins to blacken, and olefiant gas to be evolved.

To obviate these difficulties, a very beautiful process, the *continuous process*, has been introduced. It consists in taking a mixture of eight parts by weight of sulphuric acid and five of alcohol, specific gravity ·834, the boiling point of which is about 300° F. This is brought to that temperature, and alcohol of the same density is allowed slowly to flow into the mixture, the boiling point being steadily kept as near 300° F. as possible, and the mixture maintained in a state of violent ebullition. Water and ether distill over together, and may be passed through a Liebig's condenser; they collect in the receiver in separate strata, or, if this does not take place at first, the addition of a little water in the receiver insures it.

In this manner a very large quantity of alcohol may be converted into ether and water by the action of a limited amount of sulphuric acid; and in a similar manner, by adjusting the boiling point so as to be between 320° and 330° F., olefiant gas may be continuously obtained. All therefore, that is required, is to convey the alcoholic vapor through a mixture of oil of vitriol with half its weight of water, which has the required boiling point. In this process the acid does not blacken, and it is therefore much more advantageous than that described for the preparation of olefiant gas in Lecture LV.

Cloride of Olefiant Gas—Dutch Liquid ($C_4H_4Cl_2$)—is prepared by mixing equal volumes of chlorine and olefiant gas in a large glass globe. It is a colorless and fragrant liquid, soluble in alcohol and ether, but less so in water. It boils at 180° F., and when acted on by a solution of caustic potash in alcohol, it yields chloride of potassium and a substance C_4H_3Cl, which, on being cooled by a freezing mixture, condenses into a liquid. This liquid, brought in contact with chlorine, absorbs that substance, and yields a new compound, C_4H_3Cl, which may again be decomposed

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Describe the continuous process for the preparation of ether. Describe the continuous process for preparing olefiant gas. How is Dutch liquid prepared?

by an alcoholic solution of potash into chloride of potassium and a new volatile body, $C_4H_2Cl_2$.

There is an iodide and a bromide of olefiant gas, which possess a constitution analogous to the chloride.

When chlorine gas is made to act upon Dutch liquid three different substances may be successively formed by the gradual abstraction of hydrogen, and its equivalent substitution by chlorine. These substances are as follow:

Dutch liquid . . . . $C_4H_4Cl_2$.
(1.) . . . . . $C_4H_3Cl_3$.
(2.) . . . . . $C_4H_2Cl_4$.
(3.) . . . . . $C_4\ \ Cl_6$.

The first and second of these products are volatile liquids, the third is the perchloride of carbon, in which it appears that all the four atoms of hydrogen in the Dutch liquid have been removed, and their places occupied by four atoms of chlorine. This *perchloride of carbon* is a white crystalline body, soluble in alcohol and ether. Its melting point is 320° F. By passing its vapor through a red-hot porcelain tube, it is decomposed, yielding C_4Cl_4, and free chlorine, and this again gives rise to *subchloride of carbon*, C_4Cl_2, by being passed through an ignited porcelain tube at a white heat. The former of these bodies is a colorless liquid, and the latter a silky solid.

Heavy Oil of Wine (C_4H_9O, $2SO_3$) may be procured by the destructive distillation of sulphovinate of lime, or by distilling two and a half parts of oil of vitriol and one of spirit of wine. It is a colorless liquid, heavier than water, and having an odor of peppermint. Boiled with water, it yields sulphovinic acid, and *Light* or *Sweet Oil of Wine*, a substance which, after standing a few days, deposits white inodorous crystals of *Etherine*, C_4H_4. The residue, which still remains liquid, is *Etherole*, C_4H_4. It is a yellowish liquid, lighter than water, and soluble in alcohol and ether.

Sulphate of Carbyle (C_4H_4, $4SO_3$) arises when the vapor of anhydrous sulphuric acid is absorbed by pure alcohol. It is a white crystalline body. When dissolved in alcohol and water added, the solution neutralized by carbonate of baryta, filtered, concentrated, and then mixed with alcohol,

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What is the nature of the series of bodies arising from the action of chlorine on Dutch liquid? Under what circumstances does the heavy oil of wine form? How is sweet oil of wine prepared? What are etherine and etherole? When the vapor of anhydrous sulphuric acid is passed into pure alcohol, what is the result?

the *Ethionate of Baryta* precipitates. This, when decomposed by dilute sulphuric acid, yields *Hydrated Ethionic Acid*, the constitution of which is $C_4H_5O,\ 4SO_3 + 2HO$. Ethionic acid yields a series of salts, many of which can be obtained in crystals. On being boiled, solution of ethionic acid yields sulphuric acid and *Isethionic*, the peculiarity of which is, that it is isomeric with sulphovinic acid, both containing $C_4H_5O,\ 2SO_3 + HO$.

LECTURE LXXIV.

OXYDATION OF ALCOHOL.—*The Acetyle Group.—Aldehyde.—Its Preparation and Properties.—Aldehydic Acid.—Davy's Flameless Lamp.—Acetal produced by Platinum Black.—Acetic Acid, Production of.—Nature of the Change from Alcohol to Acetic Acid.—Salts of Acetic Acid.*

It has been already stated (Lecture LXXII.), that when alcohol is burned in contact with oxygen gas or atmospheric air, the sole products of the combustion are carbonic acid gas and water. But when the oxydation is partial, the hydrogen is removed by preference, and a new series of bodies is the result, designated as

The Acetyle Series.

Acetyle, C_4H_3 . . . . $= Ac.$
Oxide of acetyle . . . . $= AcO.$
Hydrated oxide of acetyle (aldehyde) . . $= AcO + HO.$
Acetylous acid (aldehydic acid) . . . . . $= AcO_2 + HO.$
Acetic acid . . . . $= AcO_3 + HO.$

Acetyle is an ideal body, differing from ethyle by containing only three atoms of hydrogen instead of five. Its oxide, also, has not yet been insulated.

Hydrated Oxide of Acetyle—Aldehyde—may be obtained by distilling two parts of the compound of aldehyde and ammonia, dissolved in two parts of water, with a mixture of three of oil of vitriol and four of water, and redistilling the product from chloride of calcium at a low temperature. It is a colorless liquid, of a suffocating odor. Its density is ·790, its boiling point 72° F. It is soluble in water and

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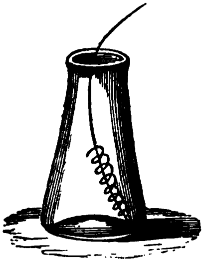
How are ethionic and isethionic acids prepared? What is acetyle? How is aldehyde prepared? What are its properties?

alcohol. It slowly oxydizes in the air, and more rapidly under the influence of the black powder of platinum, producing acetic acid. Heated with caustic potash, it yields aldehyde resin, a brown body of a resinous aspect. Aldehyde has received its name from the circumstance that it contains the elements of alcohol *minus* two atoms of hydrogen (*Alcohol Dehydrogenatus*).

When pure aldehyde is kept for a length of time at 32° F. in a close vessel, it yields *Elaldehyde*, a substance isomeric with itself, but possessing different properties, the specific gravity of its vapor, for example, being three times that of the vapor of aldehyde. From it there is also produced, at common temperatures, a second isomeric body, *Metaldehyde.*

Aldehydic Acid may be obtained by digesting oxide of silver with aldehyde, and precipitating the metal with sulphureted hydrogen. It contains one atom of oxygen less than acetic acid, and is one of the products of the slow combustion of ether in Davy's flameless lamp, which may be made by putting a small quantity of ether in a jar (*Fig.* 276), and suspending in the vapor, as it mixes with atmospheric air, a coil of platina wire which has recently been ignited. The wire remains incandescent as long as any ether is present. The same result is obtained by putting a spiral of platina wire, or a ball of spongy platina, over the wick of a spirit lamp, the lamp being lighted for a short time, and then blown out; the platinum continues incandescent, evolving a peculiarly acrid vapor.

Fig. 276.



Acetal ($C_8H_9O_3$), containing the elements of ether and aldehyde, is produced by the oxydation of vapor of alcohol by black powder of platinum, the alcohol being placed in a jar, with moistened platinum black in a capsule above it. In the course of several days the alcohol will be found to have become sour; it is then to be neutralized with chalk and distilled. Chloride of calcium separates an oily liquid

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From what is the name of aldehyde derived? Under what circumstances do elaldehyde and metaldehyde form? What is Davy's flameless lamp? Mention some of its products. What is the constitution of acetal? How may it be prepared by platinum black?

from the distilled product. This, on being distilled at a temperature of 200° F., yields acetal. It is a colorless and aromatic liquid, lighter than water, and boiling at 203° F. It yields, under the influence of an alcoholic solution of caustic potash, by absorbing oxygen from the air, resin of aldehyde.

Acetic Acid—Pyroligneous Acid—Vinegar ($C_4H_3O_3 + HO$).—When dilute alcohol is dropped on platina black, oxydation takes place, and the vapors of acetic acid are formed. On the large scale it is also formed by allowing a mixture of alcohol, water, and a small quantity of yeast, *b*, *Fig.* 277, to flow over wood shavings which have been steeped in vinegar contained in a barrel through which atmospheric air is allowed to circulate by the apertures *c*, *c*, *c*. The temperature rises, and the acetification goes on with rapidity, the product being collected in the receiver, *d*. Vinegar, also, is formed by the spontaneous souring of wines or beer containing ferment, and kept in a cask to which atmospheric air has access. During the destructive distillation of dry wood, acetic acid (hence called pyroligneous acid) in an impure state is found among the products.

Fig. 277.

The strongest acetic acid may be made by distilling powdered anhydrous acetate of soda with three times its weight of oil of vitriol. The product is then re-distilled, and exposed to a low temperature, when crystals of hydrated acetic acid form; the fluid portion is poured off, and the crystals suffered to melt. It is a colorless liquid, which crystallizes below 60° F.; has a very pungent odor, and, placed on the skin, blisters it; boils at 248° F., the vapor being inflammable. It dissolves in water, alcohol, and ether; and in a less pure state, as vinegar, its taste, odor, and applications are well known. If its constitution be compared with that of alcohol,

Alcohol	$C_4H_6O_2$,
Acetic acid	$C_4H_4O_4$,

it is seen to differ from that substance in the circumstance that two hydrogen atoms have been removed from the al-

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Mention some of the different methods by which acetic acid may be made. Why is it sometimes called pyroligneous acid? What change does alcohol undergo in passing into acetic acid?

cohol, and their places taken by two oxygen atoms. Hence the various processes for its production are easily explained. Acetic acid gives rise to several important salts.

Acetate of Potash ($KO, C_4H_3O_3$) is obtained by neutralizing acetic acid with carbonate of potash, evaporating to dryness, and fusing. This salt is very deliquescent, and has an alkaline reaction.

Acetate of Soda is made on the large scale by saturating the impure pyroligneous acid formed in the destructive distillation of wood, with lime, and then decomposing the acetate of lime with sulphate of soda. The sulphate of lime precipitates, the solution being crystallized, and the crystals subsequently purified by draining, fusing, solution, and recrystallization. The crystals effloresce in the air, and are soluble in water and alcohol.

Acetate of Ammonia—Spirit of Mindererus.—The solution is made by saturating acetic acid with carbonate of ammonia, and the solid by distilling acetate of lime and hydrochlorate of ammonia; the acetate of ammonia passes over, and chloride of calcium is left.

Acetate of Alumina is made by the decomposition of a solution of alum by acetate of lead. It is much used by dyers as a mordant.

Acetates of Lead.—1st. *Neutral Acetate* (*Sugar of Lead*) may be made by dissolving litharge in acetic acid. It occurs in colorless prismatic crystals, and also in crystalline masses. It has a sweetish, astringent taste, from which its commercial name is derived. It is soluble in about its own weight of cold water. The crystals effloresce in the air. 2d. *Subacetates of Lead—Sesquibasic Acetate*—is formed by partially decomposing the neutral acetate by heat. Its solution is known as *Goulard's Water.* Two other subacetates may be made by the action of ammonia on the neutral salt. Their solutions have an alkaline reaction, absorb carbonic acid from the air, and give rise to a precipitate of the basic carbonate.

Acetates of Copper.—1st. *Neutral Acetate—Distilled Verdigris*—made by dissolving verdigris in hot acetic acid. On cooling, it yields green crystals, soluble both in water

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Mention some of the more important salts of acetic acid? How is the acetate of soda made? What is the spirit of Mindererus? For what purpose is acetate of alumina used? What varieties of acetate of lead are there, and how are they formed? What are the varieties of acetate of copper?

and alcohol. It is used as a paint. 2d *Bibasic Acetates f Copper—Verdigris*—may be made by the action of vinegar and air conjointly on metallic copper. Verdigris is a mixture of several acetates, one of which may be obtained by digesting it in warm water; a second arises on boiling this; the insoluble residue of the verdigris contains a third.

LECTURE LXXV.

DERIVATIVES OF ACETYLE.—THE KAKODYLE GROUP.—*Chloracetic Acid.—Acetone.—Chloral and Heavy Muriatic Ether.—Substitutions of Chlorine in Light Muriatic Ether.—Sulphur-alcohol.—Its Relations to Mercury.—Xanthic Acid.—The Kakodyle Group.—Oxide—Chloride.—Kakodylic Acid.*

CHLORACETIC *Acid* ($C_4HO_4Cl_3$).—This remarkable body is formed when a small quantity of crystallized acetic acid is exposed to the sunshine in a jar-full of chlorine gas. The crystals which form on the inside of the vessel are to be dissolved in water, and the solution evaporated in vacuo with capsules containing caustic potash and oil of vitriol. A little oxalic acid is first deposited, and then the chloracetic acid crystallizes as a colorless and deliquescent body, with a powerfully acid taste, and capable of corroding the skin. It melts at 115° F., and boils at 390°. By comparing its constitution with that of acetic acid, it will be seen that in its formation three atoms of chlorine have been substituted for three of hydrogen. It yields an extensive series of salts.

Acetone—Pyroacetic Spirit (C_3H_3O)—may be made by passing acetic acid vapor through a red-hot iron tube, or by the distillation of dry acetate of lead. It is a limpid, colorless, and volatile liquid, boiling at 132°, burns with a bright flame, and is soluble in water and alcohol. Nordhausen oil of vitriol, distilled with acetone, abstracts from it one atom of water, yielding an oily body, the constitution of which is C_3H_2; it is lighter than water, and has an odor of garlic.

Sir R. Kane considers acetone to be the hydrated oxide

How is chloracetic acid made? What is the relationship between acetic and chloracetic acid? What is the mode of preparing pyroacetic spirit?

of an ideal radical, *Mesityle*, C_6H_5, and has been able to produce the oxide and chloride of mesityle. Zeise also discovered a compound consisting of the oxide of mesityle and bichloride of platinum.

CHLORAL ($C_4HCl_3O_2$).—When dry chlorine is passed into anhydrous alcohol, and the action finished by the aid of heat, hydrochloric acid is produced; and on its ceasing to appear, if the product be agitated with three times its volume of oil of vitriol, and the mixture warmed, an oily liquid floats on the acid: this is chloral. It may be purified by successive distillation from oil of vitriol and quicklime. It is an oily, colorless liquid, which causes a flow of tears, leaves a transient greasy stain upon paper, has a density of 1·502, boils at 201°, is soluble in water and alcohol; it yields no precipitate with nitrate of silver. When kept for a length of time in a sealed tube, it spontaneously becomes a white, solid, insoluble chloral. In this condition it is little soluble in water, and reverts to its other state by being warmed.

If chlorine acts on alcohol containing water, ***heavy Muriatic Ether*** is formed. It is a colorless and volatile liquid.

The action of chlorine upon common ether, and also on the compound ethers, is very interesting. It consists in the gradual removal of hydrogen, chlorine being substituted for it. This, in many instances in which the aid of the sunlight is resorted to, terminates in the entire removal of the hydrogen. In the compound ethers it is the basic hydrogen which is removed, while that of the acid escapes, as in the case of *chlorureted acetic* and *chlorureted formic* ethers. When the vapor of light hydrochloric ether is acted upon by chlorine gas, a complete series of compounds may be obtained, the hydrogen eventually disappearing:

Hydrochloric ether	C_4H_5Cl;
Monochlorureted hydrochloric ether . .	$C_4H_4Cl_2$;
Bichlorureted “ “ . .	$C_4H_3Cl_3$;
Trichlorureted “ “ . .	$C_4H_2Cl_4$;
Quadrichlorureted “ “ . .	$C_4H\ Cl_5$;
Perchloride of carbon	$C_4\ \ Cl_6$;

furnishing, therefore, a very striking instance of the doctrine of substitution.

Mercaptan—Sulphur-alcohol ($C_4H_6S_2$)—is prepared by saturating a solution of caustic potash, specific gravity 1·3,

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What is mesityle? What is chloral? Under what circumstances does insoluble chloral form? Describe the successive action of chlorine upon ether. How is mercaptan prepared?

with sulphureted hydrogen, and distilling it with an equal volume of sulphovinate of lime of the same density. It passes over with water, on the surface of which it floats as a colorless liquid, specific gravity ·842, soluble in alcohol. It boils at 97°, smells like onions, and burns with a blue flame. Mercaptan corresponds to alcohol in which all the oxygen has been replaced by sulphur; but in its action on metallic oxides it answers to the hydruret of a compound radical, $C_4H_5S_2$. Thus, with peroxide of mercury, it forms a mercaptide with the production of water; and this may be decomposed by sulphureted hydrogen, sulphuret of mercury subsiding, and mercaptan being reproduced. Mercaptan derives its name from its strong affinity for mercury (*Mercurium Captans*).

Xanthic Acid ($C_6H_5S_4O+HO$).—Hydrate of potash is to be dissolved in twelve parts of alcohol, specific gravity ·800, and bisulphuret of carbon dropped into the solution until it ceases to have an alkaline reaction. On cooling to zero, the xanthate of potash crystallizes: it is to be dried in vacuo. It is soluble in water and alcohol, but not in ether; and from it xanthic acid may be procured by the action of dilute hydrochloric acid. Xanthic acid is an oily liquid, heavier than water, which first reddens and then bleaches litmus paper. At 75° it is decomposed into alcohol and bisulphuret of carbon. It is also decomposed by the action of the air.

KAKODYLE ($C_4H_6As = Kd$) is a compound radical, which gives rise to an extensive group of bodies, in which it acts the part of a metal.

The Kakodyle Group.

Kakodyle, C_4H_6As . . . . $= Kd.$
Oxide of kakodyle . . . . $= KdO.$
Chloride " . . . . $= KdCl.$
Iodide " . . . . $= KdI.$
Sulphuret " . . . . $= KdS.$
&c. &c.

Kakodyle may be obtained by decomposing the chloride of kakodyle with metallic zinc in an apparatus filled with carbonic acid gas, and may be purified by redistillation from zinc, similar precautions being taken to exclude atmospheric air. It is a colorless liquid, of a powerful odor, taking fire

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What remarkable qualities does mercaptan possess? From what is its name derived? What is the process for preparing xanthic acid? What is its action on litmus paper? What is kakodyle? How may it be isolated.

on the contact of air, oxygen gas, or chlorine; boils at 338°, crystallizes at 21°, and is decomposed by a red heat into olefiant gas, light carbureted hydrogen, and arsenic.

Oxide of Kakodyle—Alkarsine—Cadet's Fuming Liquor—is prepared by the distillation of acetate of potash and arsenious acid, receiving the products in an ice-cold vessel, the temperature being finally carried to a red heat. The oxide comes over in an impure state, sinking to the bottom of the other products. It is to be decanted, washed with water, boiled, and then distilled in a vessel full of hydrogen from hydrate of potash. It is a colorless liquid, specific gravity 1·462, boils at 300°, and solidifies at 9°; is sparingly soluble in water, but more so in alcohol; is excessively poisonous, possessing a concentrated smell like garlic. Heated in the air, it burns, producing carbonic acid, water, and arsenious acid.

Chloride of Kakodyle may be procured by the action of a dilute solution of corrosive sublimate on a dilute alcoholic solution of oxide of kakodyle; a white precipitate falls, which, distilled with strong hydrochloric acid, yields corrosive sublimate, water, and the chloride of kakodyle passes over. When purified by chloride of calcium, and distilled in an atmosphere of carbonic acid, it is a colorless liquid, of a dreadful odor, heavier than water, and insoluble therein, but soluble in alcohol. It is very poisonous. It boils a about 212°, the vapor taking fire in the air.

Kakodylic Acid—Alcargen ($Kd . O_3$)—may be made by the action of oxide of mercury upon oxide of kakodyle under the surface of water, at a low temperature. Kakodylic acid forms crystals which deliquesce in the air, are soluble in water and alcohol, but not in ether. It is not acted upon by oxydizing agents, such as nitric acid, but is reduced to oxide of kakodyle by several deoxydizing bodies. It is not poisonous.

Kakodyle furnishes a complete series of bodies: the iodide, sulphuret, cyanide, and a substance isomeric with the oxide, which has the name of parakakodylic oxide.

What are alkarsine and Cadet's fuming liquor? How is it prepared, and what are its properties? What is the process for preparing the chloride of kakodyle? What are its properties? What is the constitution of alcargen?

LECTURE LXXVI.

The Wood-Spirit Group.—*Methyle.—Its Oxide and Hydrated Oxide.—Salts of Methyle.—Formic Acid, natural and artificial Production of.—Derivatives of Wood Spirit.—Substitutions of Chlorine in Oxide of Methyle.—Substitutions in Chloride of Methyle.*

In the destructive distillation of wood in the preparation of pyroligneous acid, there passes over a body to which the name of wood spirit has been given. This is the hydrated oxide, or alcohol of an ideal compound radical, passing under the name of methyle.

The Methyle Group.

Methyle, C_2H_3 . . . . . $= Me$.
Oxide of methyle . . . . $= MeO$.
Hydrated oxide . . . . . $= MeO + HO$.
Chloride . . . . $= MeCl$.
&c. &c.

Oxide of Methyle—Methylic Ether—Wood Ether (C_2H_3O).—This substance is made from the hydrated oxide on the same principle that ether is obtained from alcohol: one part of wood spirit and four of oil of vitriol being heated in a flask, the vapor is passed through a small quantity of caustic potash solution, and received at the mercurial trough. It is a permanently elastic gas, colorless, and has a specific gravity of 1·617, burns with a pale flame, is very soluble in water, which takes up thirty-three times its volume of it, and yields it unchanged when heated.

Hydrated Oxide of Methyle—Wood Spirit—Pyroxylic Spirit—may be separated from crude wood vinegar by distillation. It passes over with the first portions along with a little acid, which, being neutralized with hydrate of lime, the wood spirit may be separated from the oil which floats on its surface, and redistilled. The product thus obtained may be rectified in the same manner as common alcohol, and rendered anhydrous by quicklime. It is then a colorless liquid, of a hot taste and peculiar smell. It boils at

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Under what circumstances is wood spirit produced? What is its ideal compound radical? How is the oxide of methyle prepared, and what is its form? What is the constitution of pyroxylic spirit? What are its properties?

152°, and has a specific gravity of ·798 at 68°. It is soluble in water, dissolves resins and oils, and may be burned like spirit of wine. It then exhales a peculiar odor.

Chloride of Methyle ($MeCl$) may be made from the reaction of sulphuric acid upon common salt and wood spirit. It is a colorless gas, which may be collected over water; has a density of 1·731. It has a peculiar odor, is inflammable, and may be decomposed by passing through a red-hot tube.

Sulphate of Oxide of Methyle (MeO, SO_3) may be prepared by distilling one part of wood spirit with eight or ten of oil of vitriol; the product is to be washed with water, and redistilled from caustic baryta. It is an oily, neutral liquid, smelling like garlic; specific gravity 1·324. It boils at 370°. It is not soluble in water, but is decomposed by that liquid, especially at the boiling temperature, into sulphomethylic acid and hydrated oxide of methyle. It is to be observed, that in the series of wine alcohol there is no compound corresponding to this.

Nitrate of Oxide of Methyle (MeO, NO_5) is obtained by the action of a mixture of wood spirit and oil of vitriol upon nitrate of potash. It is a colorless liquid, heavier than water; boils at 150°; burns with a yellow flame. Its vapor explodes when heated. In a solution of caustic potash, it decomposes into nitrate of potash and wood spirit.

Oxalate of Oxide of Methyle (MeO, C_2O_3) is made by distilling oxalic acid, wood spirit, and oil of vitriol. The liquid which is collected is allowed to evaporate; it yields crystals of the oxalate. When pure, it is colorless; melts at 124°, and boils at 322°. It is decomposed by hot water into oxalic acid and wood spirit, by solution of ammonia into oxamide and wood spirit.

Sulphomethylic Acid ($MeO, 2SO_3 + HO$), the compound corresponding to sulphovinic acid, and prepared in the same way, by substituting wood spirit for alcohol. It is thus procured as a sirup or in small crystals, soluble in water and alcohol. It is an instable body, and possesses many analogies with sulphovinic acid.

Formic Acid ($C_2HO_3 + HO$).—This acid, in the wood-

For what purposes may pyroxylic spirit be used? How is the chloride of methyle prepared? In the wine series, is there any compound analogous to sulphate of oxide of methyle? How is the nitrate obtained, and what are its properties? Describe the preparation of the oxalate and of sulphomethylic acid What is the constitution of formic acid?

spirit series, is the analogue of acetic acid in the alcohol series. It may be procured on principles similar to those involved in the preparation of acetic acid, as by the gradual oxydation of the vapor of wood spirit in the air under the influence of black platinum. In a dilute state it may be prepared by distilling one part of sugar, three of peroxide of manganese, and two of water, with three parts of sulphuric acid, diluted with an equal weight of water. The liquid which distills is to be neutralized by carbonate of soda, purified by animal charcoal, and redistilled along with sulphuric acid. It occurs naturally in the bodies of red ants, and hence has obtained the name of formic acid. From the distillation of those animals it was originally procured.

Anhydrous formic acid (C_2HO_3) obviously contains the elements of two atoms of carbonic oxide and one of water. It yields two hydrates, respectively containing one and two atoms of water. The first, for which the formula has already been given, is procured by the action of sulphureted hydrogen on formiate of lead. It is a colorless liquid, of a strong odor; boils at 212°, and crystallizes below 32°. It is inflammable, and has a specific gravity of 1·235. It blisters the skin. Formic acid yields a complete series of salts.

Chloroform (C_2HCl_3) is made by distilling wood spirit with a solution of chloride of lime. It is a colorless liquid; specific gravity 1·48; boils at 141°. It burns with a green flame, and is decomposed by an alcoholic solution of potash into chloride of potassium and formiate of potash. The relationship between formic acid and chloroform is obvious: it consists in the substitution of three atoms of chlorine for three of oxygen. There are also two analogous compounds:

Bromoform	C_2HBr_3.
Iodoform	C_2HI_3.

Formomethylal ($C_3H_4O_2$) is prepared by distilling wood spirit, oxide of manganese, and dilute sulphuric acid. On saturating the product with potash, formomethylal separates as a colorless oily liquid: specific gravity ·855; boils at 107°, and soluble in water.

Methyle-mercaptan.—Formed as the common mercaptan, by substituting sulphomethylate of potash for sulphovinate of lime. It is analogous to common mercaptan.

How is it procured? From what circumstance is its name derived? What are its properties? How is chloroform obtained? What is the process for preparing formomethylal?

When chlorine is made to act on the oxide of methyle at common temperatures, it removes one of the hydrogen atoms; and by continuing the action, a second may be taken away, and the process of substitution, as shown in the following series, may be carried so far as to end in the removal of oxygen and the production of chloride of carbon.

Oxide of methyle		C_2H_3O.
1st substitution		C_2H_2O, Cl.
2d "		$C_2H\ O, Cl_2$.
3d "		$C_2\ \ O, Cl_3$.
4th "	(chloride of carbon)	$C_2\ \ \ Cl_4$.

Other methylic compounds furnish similar series, thus ·

Chloride of methyle		C_2H_3Cl.
1st substitution		$C_2H_2Cl_2$.
2d "	(chloroform)	$C_2H\ Cl_3$.
3d "	(chloride of carbon)	$C_2\ \ Cl_4$.

LECTURE LXXVII.

THE POTATO-OIL GROUP.—*Fusel Oil.—Chloride of Amyle.—Sulphamylic Acid.—Amilen.—Relations of Valerianic Acid.*

THE BENZYLE GROUP.—*Oil of Bitter Almonds.—Benzoic Acid.—Sulphobenzoic Acid.—Chloride of Benzyle.—Benzamide.*

IN the distillation of brandy from potatoes, a volatile oil passes over. It is regarded as the hydrated oxide of an ideal compound radical, which passes under the name of *Amyle*, having the constitution $C_{10}H_{11}$.

The Potato-Oil Group.

Amyle, $C_{10}H_{11}$ $= Ayl$.
Amyle ether $= AylO$.
Amyle alcohol (potato oil) $= AylO + HO$.
Chloride of amyle $= AylCl$.
&c. &c.
Amilen $C_{10}H_{10}$.
Valerianic acid $C_{10}H_9O_3$.

Of these, amyle and its oxide, amyle-ether, are ideal.

Hydrated Oxide of Amyle—Amyle Alcohol—Potato Oil—Fusel Oil ($C_{10}H_{11}O + HO$).—This substance passes

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Describe the series of substitutions of chlorine on the oxide of methyle. Describe the analogous substitutions with chloride of methyle? What is the imaginary radical of the potato-oil group? What are the nature and relations of fusel oil?

over toward the end of the first distillation of potato spirit, and communicates to it a milky aspect. On standing, it floats on the surface, and may be purified by washing with water, drying with chloride of calcium, and redistillation. It is a fluid oil of a suffocating odor, which acts powerfully on the animal system. Its specific gravity is ·818; it boils at 269°.

Chloride of Amyle ($AylCl$) is made by distilling equal weights of potato oil and perchloride of phosphorus, washing with potash water, and redistilling from chloride of calcium. It as an aromatic liquid, boils at 215°, and burns with a green flame. Under the influence of sunshine, eight of its hydrogen atoms may be removed, eight chlorine atoms being substituted for them, $C_{10}H_{11}Cl$ yielding $C_{10}H_3Cl_9$, forming chlorureted chloride of amyle.

The *Iodide* and *Bromide of Amyle* are compounds analogous to the chloride.

Acetate of Oxide of Amyle is obtained by distilling acetate of potash, potato oil, and sulphuric acid. It is a colorless liquid, which boils at 257°.

Sulphamilic Acid ($AylO,\ 2SO_3H + O$) is generated when sulphuric acid is made to act on an equal weight of potato oil. From this, by the successive action of carbonate of baryta and sulphuric acid, it may be procured by operating on the same principles as for sulphovinic acid, to which, both in constitution and properties, it is the analogue. It is a sirupy or crystalline body, and is decomposed by ebullition into potato oil and sulphuric acid.

Amilen ($C_{10}H_{10}$) is obtained by the action of anhydrous phosphoric acid on potato oil; it is an oily liquid, which boils at 320°. In constitution and position, it therefore occupies, in the amyle series, the same situation that olefiant gas does for the wine-alcohol series, and, indeed, is isomeric with that body.

Valerianic Acid ($C_{10}H_9O_3$) bears the same relation to the amyle group which acetic acid does to the wine-alcohol group, or formic acid to the wood-spirit group. It is formed when warm potato oil is dropped on platinum black in contact with the air. It occurs naturally in the root of the *Valeriana Officinalis*, but is best made by heating potato

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What are the properties of the chloride of amyle? To what substance is sulphamilic acid analogous? What relation is there between amilen and olefiant gas? What is the relation between acetic and valerianic acids? From what natural source may the latter be derived?

oil in a flask, with a mixture of quicklime and hydrate of potash, for several hours at a temperature of 400°. The white residue is immersed in cold water, and distilled with a slight excess of sulphuric acid, so as to drive off hydrated valerianic acid and water. It is a colorless oil of an acid taste, combustible, and boiling at 347°. When acted upon by chlorine in the dark, and the action aided by heat, it gives rise to *Chlorovalerisic Acid* ($C_{10}H_6Cl_3O_3 + HO$), in which there has been a removal of three hydrogen atoms and a substitution of three of chlorine. Under the influence of the sunshine, by the same process, another hydrogen atom is removed, and *Chlorovalerosic Acid* forms, its constitution being $C_{10}H_5Cl_4O_3 + HO$.

The Benzyle Group.

Benzyle, $C_{14}H_5O_2$ . . . . $= Bz$.
Hydruret of benzyle . . . . $= Bz + H$.
Oxide of benzyle (benzoic acid) . . . . $= Bz + O$.
Chloride . . . . $= Bz + Cl$.
&c. &c.

Of this series, benzyle, the radical, is an ideal body. It is a radical which discharges the functions of a metallic body, giving rise to oxides, chlorides, iodides, &c., as the table shows.

Hydruret of Benzyle—Oil of Bitter Almonds (BzH)—is obtained by the distillation of bitter almonds, from which the fixed oil has been expressed, with water, and arises from the action of the water upon *Amygdaline* contained in the seed. It may be purified by distillation from protochloride of iron with hydrate of lime in excess, and is a colorless liquid of an agreeable odor, slightly heavier than water, and also slightly soluble therein, but very soluble in alcohol and ether. It boils at 356°. In the air it passes into benzoic acid by absorbing oxygen.

Oxide of Benzyle—Benzoic Acid ($BzO + HO$.)—This acid is obtained by sublimation from gum benzoin, that substance being placed in a shallow vessel, over the top of which a cover of filtering paper is pasted, and this covered by a taller cylinder of stouter paper. On heating, the vapors pass through the filtering paper, and, condensing in feathery crystals in the space above, fall down upon the pa-

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How is valerianic acid made artificially? What is the successive action of chlorine upon it? What is the radical of the benzyle series? What is oil of bitter almonds? From what substance does it arise? What is benzoic acid? By what processes may it be prepared?

per and are retained by it. A better method is to boil a mixture of the gum with hydrate of lime, filter, concentrate the solution, add hydrochloric acid, and the benzoic acid crystallizes in thin plates on cooling. It may be subsequently sublimed. When pure it has no odor. It melts at 212°, and boils at 462°. Its vapor excites coughing. It is much more soluble in hot than in cold water. It forms a series of salts, and is sometimes used for the separation of iron from other metals.

Sulphobenzoic Acid ($C_{14}H_5O_3, SO_3 + 2HO$), a bibasic acid, formed by the action of anhydrous sulphuric acid upon benzoic acid, the mass being dissolved in water and neutralized by carbonate of baryta. On filtering, and adding hydrochloric acid to the hot solution, on cooling the sulphobenzoate of baryta crystallizes, which may be decomposed by dilute sulphuric acid. It is a white crystalline mass.

Chloride of Benzyle ($BzCl$).—When chlorine gas is passed through oil of bitter almonds, hydrochloric acid is formed, and, after expelling the excess of chlorine by heat, chloride of benzyle remains. It is a colorless liquid, of a disagreeable odor, heavier than water, combustible, and decomposed by boiling water into benzoic and hydrochloric acids.

Benzamide ($C_{14}H_7NO_2$) is formed by the action of chloride of benzyle on dry ammonia, the hydrochlorate of ammonia being removed from the resulting white mass by cold water. From a solution in boiling water, the benzamide crystallizes. It melts at 239°. It corresponds in its chemical relations to oxamide.

Hydrobenzamide ($C_{42}H_{18}N_2$), made by the action of pure oil of bitter almonds on solution of ammonia, the product being washed with ether, and from its alcoholic solution this substance crystallizes; but when impure almond oil is employed, three other compounds may be obtained: they are benzhydramide, azobenzoyle, and nitrobenzoyle.

What is the process for preparing sulphobenzoic acid? How is the chloride of benzyle made? How are benzamide and hydrobenzamide formed?

LECTURE LXXVIII.

THE SALICYLE AND CINNAMYLE GROUPS.—*Benzoine, Benzone, Benzine.*—*Hippuric Acid.*—THE SALICYLE GROUP.—*Artificial Formation of Oil of Spiræa.*—*Compounds of Salicyle.*—*Melanic Acid.*—THE CINNAMYLE GROUP.—*Compounds of Cinnamyle.*

BENZOINE ($C_{14}H_6O_2$), a body isomeric with bitter almond oil. It is found in the residue after purifying that oil from hydrocyanic acid by distillation from lime and oxide of iron, and may be obtained by dissolving out those bodies by hydrochloric acid. It crystallizes from an alcoholic solution, on cooling, in colorless crystals, which melt at 248°. It dissolves in an alcoholic solution of caustic potash, which, by boiling until the violet color has disappeared, furnishes benzilate of potash, a salt from which benzilic acid may be obtained by hydrochloric acid. The constitution of *Benzilic Acid* is $C_{28}H_{11}O_5 + HO$.

Benzone ($C_{13}H_5O$) is obtained by the distillation of dry benzoate of lime at a high temperature, carbonate of lime remaining behind. The decomposition is interesting, the benzoic acid atom being divided, and yielding benzone and carbonic acid.

$$C_{14}H_5O_3 \ldots = \ldots C_{13}H_5O + CO_2.$$

Benzine ($C_{12}H_6$) arises when crystallized benzoic acid is distilled from hydrate of lime at a red heat. It is an oily liquid, and, after being separated from the water which comes over with it, is to be rectified. It boils at 187°, solidifies at 32°, and is lighter than water. In its formation the hydrated benzoic acid is resolved into benzine and carbonic acid.

$$C_{14}H_6O_4 \ldots = \ldots C_{12}H_6 + 2(CO_2).$$

Sulphobenzide ($C_{12}H_5SO_2$) is formed by taking the substance which arises from the union of benzine with anhydrous sulphuric acid, and acting upon it with an excess of

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What relation does benzoine bear to oil of bitter almonds? What is the result of the distillation of dry benzoate of lime? What is the nature of the decomposition? What is the result of the distillation of crystallized benzoic acid and hydrate of lime? What is the result of the action of anhydrous sulphuric acid and benzine?

water. The sulphobenzide, which is insoluble in that liquid, may be obtained in crystals from its ethereal solution. It melts at 212° F. From the acid liquid from which it has been separated hyposulphobenzic acid may be obtained. Its constitution is $C_{12}H_5S_2O_5 + HO$.

Nitrobenzide ($C_{12}H_5NO_4$), produced by the action of fuming nitric acid on benzine, with the aid of heat. It is an oily liquid, of a sweet taste, heavier than water, and boiling at 415°. From it *Azobenzide* ($C_{12}H_5N$) may be obtained by distillation with an alcoholic solution of caustic potash, in the form of red crystals.

Chlorbenzine ($C_{12}H_6Cl_6$) is formed by the union of benzine and chlorine in the sun-rays. When distilled, the solid yields hydrochloric acid and a liquid, *Chlorbenzide* ($C_{12}H_3Cl_3$).

Hippuric Acid ($C_{18}H_8NO_5 + HO$) is found in the urine of graminivorous animals, and occurs in the urine of persons who have taken benzoic acid. It may be prepared by evaporating the fresh urine of the cow, and acidulating the concentrated liquor with hydrochloric acid; crystals of hippuric acid are deposited, which may be decolorized by bleaching liquor and hydrochloric acid. It crystallizes in square prisms, sparingly soluble in cold water, of a bitter taste and acid reaction. By a high temperature or the action of sulphuric acid, it yields benzoic acid.

THE SALICYLE GROUP.

There is contained in the bark of the willow and other trees a bitter crystalline principle, SALICINE ($C_{21}H_{13}O_{11}$). This substance may be extracted by boiling the bitter bark in water, and digesting the concentrated solution with oxide of lead to decolorize it, removing any dissolved lead by sulphureted hydrogen, and evaporating until the salicine crystallizes. It forms white needles of a bitter taste, much more soluble in hot than cold water. Distilled with bichromate of potash and sulphuric acid, it yields hydrosalicylic acid, or the artificial oil of meadow sweet, a substance containing *Salicyle*, the ideal compound radical of a series of bodies.

What is the action of nitric acid on benzine? What substance results from the union of benzine and chlorine? From what sources may hippuric acid be obtained? Under what circumstances does benzoic acid produce it? From what is salicine obtained? What is the constitution of salicyle? How may the oil of meadow sweet be made artificially?

The Salicyle Group.

Salicyle $C_{14}H_5O_4$ . . . . = *Sl.*
Hydrosalicylic acid . . . . . . = *SlH.*
Iodide of salicyle . . . . = *SlI.*
Chloride . . . . = *SlCl*
&c. &c.

Hydrosalicylic Acid—Oil of Spiræa Ulmaria, or Meadow Sweet ($C_{14}H_5O_4 + H$)—is prepared by distilling one part of salicine, one of bichromate of potash, two and a half of sulphuric acid, and twenty of water; the salicine being dissolved in one portion of the water, and the acid mixed with the rest. The yellow oil which comes over is rectified from chloride of calcium. It may also be obtained by distilling the flowers of meadow sweet with water. It is transparent, but turns red in the air. It is slightly soluble in water, and very soluble in alcohol. Its specific gravity is 1·173; it boils at 385° F. It contains the same elements as benzoic acid.

Salicylic Acid ($C_{14}H_5O_4 + O$) is obtained by the action of hydrate of potash on the foregoing body by the assistance of heat. After the disengagement of hydrogen is over, the mass is dissolved in water, and salicylic acid separates in crystals on the addition of hydrochloric acid. It is more soluble in hot than cold water, and is charred by hot oil of vitriol.

Chloride of Salicyle ($C_{14}H_5O_4Cl$) is made by the action of chlorine on hydrosalicylic acid. Its crystals are insoluble in water, but soluble in solutions of fixed alkalies, from which it separates on the addition of an acid, resisting decomposition even when boiled in caustic potash. It unites with caustic potash.

Bromide and Iodide of Salicyle also exist, but are not of interest.

Chlorosamide ($C_{42}H_{15}N_6O_5Cl_3$).—Ammoniacal gas is absorbed by the chloride of salicyle, producing a yellow body, which crystallizes from a boiling ethereal solution. It is insoluble in water. When acted upon by hot acids, it yields a salt of ammonia and chloride of salicyle; an alkali forms with it ammonia and chloride of salicyle. There is an analogous bromosamide.

Salicyluret of Potassium (*KSl*) is formed by the action

What is the constitution of salicylic acid? What is the action of ammonia on chloride of salicyle? Under what circumstances is melanic acid produced?

of oil of meadow sweet on a solution of caustic potash. It forms in yellow crystals from its alcoholic solution, and has an alkaline reaction.

Melanic Acid ($C_{10}H_4O_5$) is produced when the crystals of salicyluret of potassium are exposed in a moist state to the air. They first turn green and then black, and alcohol extracts from them melanic acid.

CINNAMYLE.

The essential oil of cinnamon is supposed to be the hydruret of an ideal compound radical, cinnamyle, analogous to benzoyle, and yielding a series.

The Cinnamyle Group.

Cinnamyle, $C_{18}H_7O_2$ . . . . $= Ci.$
Hydruret of cinnamyle (oil of cinnamon) . . . . $= CiH.$
Oxide " (cinnamic acid) . . . . $= CiO.$
Chloride " . . . . $= CiCl.$
&c. &c.

Hydruret of Cinnamyle—Oil of Cinnamon ($C_{18}H_7O_2 + H$)—is obtained by infusing cinnamon in a solution of salt, and then distilling the whole. It is heavier than water, and may be separated from that liquid by contact with chloride of calcium.

Cinnamic Acid ($C_{18}H_7O_2 + O$) is formed when oil of cinnamon is exposed to oxygen gas, the oil becoming a white crystalline mass, hydrated cinnamic acid. It may also be obtained by boiling hard Tolu balsam with hydrate of lime. The cinnamate of lime crystallizes as the solution cools, benzoate of lime remaining in solution. The crystals are decolorized by animal charcoal, and then decomposed by hydrochloric acid; from the hot solution cinnamic acid crystallizes. It melts at 248°, and boils at 560°. It is soluble in boiling water and in alcohol; is decomposed by hot nitric acid, and yields benzoic acid, with oil of vitriol and bichromate of potash.

Chlorocinnose ($C_{18}H_4Cl_4O_2$) arises from oil of cinnamon by the substitution of four atoms of chlorine for four of hydrogen, and is made by the action of chlorine on oil of cinnamon by the aid of heat. It crystallizes from its alcoholic solution in colorless needles.

What is the essential oil of cinnamon? What is the constitution of cinnamyle? How may cinnamic acid be prepared? What is the constitution of chlorocinnose, and how is it prepared?

LECTURE LXXIX.

THE NITROGENIZED PRINCIPLES.—AMMONIA *and its Salts.* —CYANOGEN.—*Preparation and Properties of Prussic Acid.—Amygdaline and Synaptase.—The Cyanides.—Oxygen Acids of Cyanogen.*

AMMONIA.—I have already described in Lecture LVI., the compounds of hydrogen and nitrogen, under the names of amidogen, ammonia, and ammonium, and have also shown the relation there is between the salts of potash and soda and those of the oxide of ammonium. This compound metal is a hypothetical body; its existence may, however, be illustrated by passing a Voltaic current through a globule of mercury in contact with moist chloride of ammonium, or by putting an amalgam of mercury and potassium in a strong solution of that salt. The mercury rapidly increases in volume, retaining its metallic aspect, becomes of the consistency of butter, with a very trivial increase of weight; the resulting substance is the *Ammoniacal Amalgam.* All attempts to insulate ammonium from it have failed.

The most important salts of ammonia are the following:

Chloride of Ammonium—Sal Ammoniac—Muriate of Ammonia—was formerly brought from Egypt, but is now made from the ammoniacal liquors resulting from the destructive distillation of animal matters, coal, &c. It is soluble in water, crystallizes in cubes or octahedrons, and sublimes below a red heat unchanged. It is decomposed by lime and potash, and is formed when the vapors of ammonia mingle with those of muriatic acid.

Nitrate of Ammonia is formed by neutralizing nitric acid with ammonia. It is deliquescent, and therefore very soluble in water. It melts at 240°, and at a higher temperature decomposes into steam and protoxide of nitrogen, as is explained in Lecture XLVI.

Carbonates of Ammonia.—The *neutral carbonate* only exists in combination. With the carbonate of water it

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What is ammonium? How is the ammoniacal amalgam prepared? From what sources is sal ammoniac derived? For what purpose is nitrate of ammonia employed?

unites, forming *Bicarbonate of Ammonia*, which may be prepared by washing the commercial *Sesquicarbonate* with water or alcohol, which leaves it undissolved. The carbonate of ammonia of commerce is prepared by sublimation from a mixture of sal ammoniac and chalk. Its constitution is not uniform, though it is commonly regarded as a sesquicarbonate.

Sulphate of Ammonia may be made by neutralizing sulphuric acid with carbonate of ammonia. It is soluble in twice its weight of cold water, and crystallizes in six-sided prisms.

Hydrosulphuret of Ammonia is made by passing sulphureted hydrogen into water of ammonia until no more is absorbed. Though colorless at first, it absorbs oxygen, and, sulphur being liberated, it turns yellow. It is of considerable use as a metallic test.

CYANOGEN. — *Bicarburet of Nitrogen* (C_2N). — The mode of preparing this remarkable body, and also its leading properties, have been described in Lecture LVI. It is of great interest in organic chemistry, as being the first distinctly established compound radical, and the best representative of the electro-negative class of those bodies.

We may call to mind that it is easily made by the decomposition of cyanide of mercury at a low red heat, is a gaseous body, soluble in water, and, therefore, must be collected over mercury. It is combustible, and burns with a purple flame.

The Cyanogen Group.

Cyanogen, C_2N	$= Cy$
Hydrocyanic acid	$= CyH$.
Cyanic acid	$= CyO$.
Fulminic acid	$= Cy_2O_2$.
Cyanuric acid	$= Cy_3O_3$.
&c.	&c.

Paracyanogen (C_2N).—When the cyanide of mercury is decomposed in the process for preparing cyanogen, a brownish substance is set free, which is paracyanogen. It is insoluble in water and alcohol, and is only remarkable in being isomeric with cyanogen.

Hydrocyanic Acid—Prussic Acid—Cyanide of Hydro-

What is the carbonate of ammonia of commerce? How is hydrosulphuret of ammonia made, and what is its use? What is the constitution of cyanogen? What interesting fact is connected with its discovery? What are its properties? What is paracyanogen?

gen (C_2N+H).—Hydrocyanic acid may be obtained in a state of purity by passing dry sulphureted hydrogen gas over dry cyanide of mercury in a tube, and conducting the vapor, which is evolved when the tube is warmed, into a vial immersed in a freezing mixture. The result of the decomposition is sulphuret of mercury and hydrocyanic acid. In a state of aqueous solution, it is best obtained by the action of dilute sulphuric acid on the ferrocyanide of potassium in a retort, and receiving the vapor in a Liebig's condenser. Having ascertained the strength of the product, it may then be diluted to the proper point. This examination may be conducted by precipitating a known weight of the acid with nitrate of silver in excess. collecting the cyanide of silver on a weighed filter, washing, drying, and reweighing, which gives the weight of the cyanide. This, divided by five, is the weight of the pure hydrocyanic acid, nearly.

Anhydrous hydrocyanic acid is a colorless and very volatile liquid, which exhales a strong odor of peach blooms; has a density of ·705; boils at 79°. It mixes with water and alcohol in any proportion. A drop of it held in the air on a glass rod becomes solidified by the rapid evaporation from its surface. In the sunlight it decomposes rapidly, producing a dark-colored substance; and the same change goes on, though much more slowly, in the dark. It is one of the most insidious and terrible poisons, a few drops producing death in a few seconds; and even its vapor, largely diluted with air, brings on very unpleasant symptoms. Under the action of strong acids it is decomposed into ammonia and formic acid, the change being very simple:

$$C_2N, H + 3HO = NH_3 + C_2HO_3.$$

Under such circumstances, hydrochloric acid yields muriate of ammonia and hydrated formic acid. Hydrocyanic acid may, to a certain extent, be preserved from spontaneous change by the presence of a minute quantity of any mineral acid.

Prussic acid may be detected by its smell, and by yielding a precipitate of Prussian blue when acted upon in solution successively by sulphate of iron, potash, and an ex-

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How may hydrocyanic acid be made? By what process can its strength be determined? What are its properties? What is the action of strong acids upon it? How may it be partially preserved from spontaneous change? How may it be detected?

cess of hydrochloric acid. The liquid in which the poison is suspected to exist should be acidulated with sulphuric acid and distilled, and the hydrocyanic acid will be found in the first portions which come over.

Amygdaline ($C_{40}H_{27}NO_{22}$).—A crystallizable substance found in bitter almonds, the kernels of peaches, &c.; is of considerable interest in connection with hydrocyanic acid, inasmuch as these organic bodies yield, when distilled with water, that substance. The change consists in the action of water upon amygdaline by the aid of an azotized ferment called *Synaptase* or *Emulsine*, which constitutes the larger portion of the pulp of almonds; the bitter almond oil at the same time makes its appearance. Amygdaline may be abstracted from the paste of bitter almonds, from which the fixed oil has been expressed, by the aid of boiling alcohol, which being subsequently distilled off, the sugar which is contained in the sirupy residue is destroyed by fermentation with yeast. The liquid being evaporated again to a sirup, is mixed with alcohol, which precipitates the amygdaline as a white crystalline powder, purified by being redissolved in alcohol and left to cool. It is soluble in hot and cold water, but sparingly soluble in cold alcohol. A weak solution of it in water, under the influence of a small quantity of the emulsion of sweet almonds, yields at once oil of bitter almonds and hydrocyanic acid. When amygdaline is boiled with an alkali, it yields *Amygdalinic Acid*, which forms a salt with the alkali, and ammonia is evolved.

Cyanide of Potassium (KCy) may be formed by the direct union of cyanogen and potassium, or by the ignition of the ferrocyanide of potassium in a close vessel. For common purposes in the arts it may be formed in a state somewhat impure by mixing eight parts of ferrocyanide of potassium, rendered anhydrous by heat, with three of carbonate of potash, also dry, and fusing the mixture in a crucible, stirring it until the fluid part of the mass is colorless. The sediment is allowed to settle, and the clear liquid poured off; it is the substance in question. Cyanide of potassium is very soluble in water, yields colorless octahedral crystals, which deliquesce in the air; it melts without

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What is amygdaline? What is the action of synaptase and water upon it? How may it be obtained? By what processes may the cyanide of potassium be made?

change at a red heat, and exhales the odor of prussic acid. It is very poisonous.

Cyanide of Mercury may be made by dissolving red oxide of mercury in hydrocyanic acid, or by the action of a solution of ferrocyanide of potassium on sulphate of mercury, the cyanide crystallizing from the filtered hot solution. It forms fine prismatic crystals, more soluble in hot than cold water. It is poisonous; and, when decomposed at a low red heat, yields cyanogen gas.

Cyanic Acid ($CyO + HO$) is procured by heating in a retort cyanuric acid deprived of its water of crystallization; a colorless liquid comes over into the receiver, which is the hydrated cyanic acid; it has a strong odor like acetic acid, and produces blisters on the skin. It is decomposed by the contact with water into bicarbonate of ammonia.

$$C_2NO, HO + 2HO \ldots = \ldots C_2O_4 + NH_3,$$

and is a very instable body, spontaneously changing in a short time into *Cyamelide*, a body of the same constitution, but a white opaque solid, insoluble in water and alcohol, and decomposed by hot oil of vitriol into carbonate of ammonia.

Fulminic Acid ($Cy_2O_2 + 2HO$) has not yet been insulated, but some of its salts, presently to be described, are characterized by the violence with which they detonate under very trivial disturbances. It is a bibasic acid.

Cyanuric Acid ($Cy_3O_3 + 3HO$) may be made by heating urea, which disengages ammonia; the residue is dissolved in hot sulphuric acid, and nitric acid added until the liquid becomes colorless: on mixing it with water, and allowing it to cool, the cyanuric acid separates. Its crystals are efflorescent; it is sparingly soluble in water, and is a tribasic acid; and, as has been already stated, at a red heat it may be distilled, and yields cyanic acid without any other product.

How may the cyanide of mercury be prepared? Exposed to heat, what does it yield? What are the constitution and properties of cyanic acid? What of fulminic acid? What of cyanuric acid?

LECTURE LXXX.

BODIES ALLIED TO CYANOGEN.—*Salts of the Oxycyanogen Acids.*—FERROCYANOGEN.—*Ferrocyanides of Hydrogen and Potassium.—Prussian Blue and Basic Blue.*—FERRIDCYANOGEN.—SULPHOCYANOGEN.—*Compounds with Hydrogen and Potassium.—Melam, Melamine, &c.*

CYANATE *of Potash* (KO, CyO) may be prepared by oxydizing cyanide of potassium by oxide of lead in an earthen crucible; the result boiled with alcohol yields, on cooling, crystals of cyanate of potash, in thin transparent plates, which undergo no change in dry air, but with moisture become converted into bicarbonate of potash and ammonia.

Cyanate of Ammonia—Urea ($C_2H_4N_2O_2$).—The vapor of hydrated cyanic acid, mixed with ammoniacal gas, yields cyanate of ammonia. The solution in water, when heated, gives off ammonia, and the cyanate changes into *Urea*, from which caustic alkalies can not disengage ammonia. Urea may also be made from the action of sulphate of ammonia or cyanate of potash.

Fulminate of Silver ($2AgO, C_4N_2O_2$) is made by dissolving silver in warm nitric acid and adding alcohol. It separates from the hot liquid in white grains, which, being washed in water, are dried in small portions on filtering paper. It detonates with wonderful violence when either struck or rubbed. It is sparingly soluble in hot water, and crystallizes from that solution on cooling. It yields, by digestion with water and metals, salts, as those of zinc and copper.

Fulminate of Mercury ($2HgO, C_4N_2O_2$) is prepared in the same manner as the foregoing, and, like it, is very explosive. It is used for making percussion caps.

Chloride of Cyanogen ($CyCl$) is prepared by the action of chlorine on moist cyanide of mercury in the dark. It is a colorless gas, soluble in water, congeals at 0°, and boils

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How is the cyanate of potash made? How may urea be formed artificially? What is the process for preparing fulminating silver, and what are its properties? For what purpose is fulminate of mercury used? What results from the action of chlorine on cyanide of mercury in the dark?

at 11°; condenses into a liquid under the pressure of four atmospheres. When kept in this condition, in sealed tubes, for a length of time, it assumes the solid state, which form may also be given to it by acting on anhydrous hydrocyanic acid by chlorine in the sun's rays; hydrochloric acid is formed, and the solid cyanide crystallizes. It exhales a peculiar odor, melts at 284°, and is soluble in alcohol and ether

FERROCYANOGEN.

Ferrocyanogen ($C_6N_3Fe = Cfy$) is an ideal compound radical.

Hydroferrocyanic Acid ($Cfy, 2H$) may be obtained by decomposing the insoluble ferrocyanide of lead by sulphureted hydrogen while suspended in water. The solution being filtered, is to be evaporated with sulphuric acid in vacuo until the acid is left solid. It may also be prepared by agitating its aqueous solution with ether, or by adding hydrochloric acid to a strong solution of ferrocyanide of potassium, and then mixing it with ether, which precipitates the acid. It is soluble in water, to which it gives a powerful acid reaction. It decomposes alkaline carbonates with effervescence, and does not dissolve oxide of mercury in the cold. In these respects, therefore, it strikingly differs from hydrocyanic acid.

Ferrocyanide of Potassium—Prussiate of Potash—($2K, Cfy + 3HO$).—This salt is made on the large scale by igniting potash, iron filings, and animal matters in an iron vessel; the mass is then acted upon by hot water, which dissolves out a large quantity of cyanide of potassium, which is converted into the ferrocyanide by the iron, and the filtered solution, on cooling, yields it in lemon-colored crystals, soluble in four parts of cold water. It is not poisonous. At a red heat it decomposes, and yields cyanide of potassium. It is a very valuable reagent; with copper it yields a chocolate precipitate; with protoxide of iron, a white; and with peroxide of iron, Prussian blue.

Common Prussian Blue ($3Cfy + 4Fe$) is prepared by precipitating a persalt of iron by solution of ferrocyanide of potassium; when dry, it is of a deep blue, with a lustre of coppery-red. It is insoluble in water, is decomposed by al-

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What is ferrocyanogen? How is hydroferrocyanic acid obtained? How is the prussiate of potash prepared? Is it poisonous? What color does it give with protoxide and peroxide of iron? What is common Prussian blue? What is its composition?

kaline solutions, which yield alkaline ferrocyanides, and precipitate oxide of iron. It is soluble in solution of oxalic acid, and then constitutes the basis of blue writing inks, which are used for steel pens. It is also much employed as a paint.

Basic Prussian Blue ($3Cfy, 4Fe + FeO_3$) is formed when the white precipitate, yielded by a protosalt of iron with ferrocyanide of potassium, is exposed to the air. As its formula shows, it is common Prussian blue, with peroxide of iron. It differs from Prussian blue in the remarkable peculiarity that it is soluble in pure water.

FERRIDCYANOGEN.

Ferridcyanogen ($C_{12}N_6Fe_2 = Cfdy$).—A hypothetical compound radical, which yields some compounds of interest.

Ferridcyanide of Potassium ($3K + Cfdy$) may be made by passing chlorine through a dilute solution of ferrocyanide of potassium until it ceases to yield a precipitate with a persalt of iron. The liquid being concentrated, yields, on cooling, deep-red crystals, the solution of which is of a greenish color. It gives no precipitate with peroxide of iron, but with the protosalts a bright blue, lighter than Prussian blue, and known as *Turnbull's Blue.*

Cobaltocyanogen, a hypothetical radical, yielding compounds analogous to the preceding bodies.

Sulphocyanogen (C_2NS_2) (Csy), a compound radical, not yet insulated with certainty. Its formula shows that it is a bisulphuret of cyanogen.

Hydrosulphocyanic Acid ($CsyH$) may be obtained by decomposing sulphocyanide of lead by sulphureted hydrogen in water. The solution is decomposed by ebullition. It has the odor of acetic acid. It yields with peroxide of iron a blood-red color.

Sulphocyanide of Potassium ($KCsy$) may be made by heating powdered ferrocyanide of potassium with half its weight of sulphur and one third of carbonate of potash, and keeping it melted for a short time. The mass is then boiled with water, which dissolves out the sulphocyanide, and the solution being concentrated, yields prismatic crystals of

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For what purposes is it used? In what respect does basic Prussian blue differ from it? What is the constitution of ferridcyanogen? What is Turnbull's blue? What are cobaltocyanogen and sulphocyanogen? What color does hydrosulphocyanic acid yield with peroxide of iron? By what process is sulphocyanide of potassium made?

the salt. It is soluble in water and alcohol, and deliquesces in the air. It melts at a red heat. Its solution with peroxide of iron yields a blood-red color.

Melam ($C_{12}H_9N_{11}$) is produced when sulphocyanide of ammonium is distilled at a high temperature, or by heating dry sulphocyanide of potassium with twice its weight of sal ammoniac. It is insoluble in water, but dissolves in strong sulphuric acid. When heated, it yields mellone and ammonia.

Melamine ($C_6H_6N_6$) is produced when melam is dissolved in a hot solution of potash. It separates on cooling. It is a basic body, uniting with acids.

Ammeline ($C_6H_5N_5O_2$) remains in the solution after the melamine has crystallized. It may be precipitated with acetic acid.

Ammelide ($C_{12}H_9N_9O_6$) is prepared by dissolving ammeline in sulphuric acid, and precipitating with alcohol.

LECTURE LXXXI.

MELLONE — UREA. — *Mellone, Preparation of.—Mellonides of Hydrogen and Potassium.—Natural and artificial Formation of Urea.—Uric Acid.—Its Properties.—Derivatives of Uric Acid.—Parabanic, Oxaluric, and Thionuric Acids.—Alloxantine.—Purpurate of Ammonia.—Xanthic and Cystic Oxides.*

MELLONE ($C_6N_4 = Me$).—If sulphocyanide of potassium be acted upon by chlorine or nitric acid, a yellow powder is deposited; this, when heated, gives off bisulphuret of carbon and sulphur, and there is left a yellowish powder, which is mellone. The relation of its constitution with cyanogen is obvious. It resists a moderate heat without change.

Hydromellonic Acid (MeH).—By adding hydrochloric acid to a hot solution of mellonide of potassium, this acid separates as a white powder on cooling. It is partially soluble in hot water, and possesses strong acid powers.

What results from the distillation of the sulphocyanide of ammonium? What are melamine, ammeline, and ammelide? How is mellone prepared? What is the action of hydrochloric acid on the mellone of potassium?

Mellonide of Potassium (KMe) may be prepared by melting ferrocyanide of potassium with half its weight of sulphur, and adding, when the fusion is complete, five per cent. of dry carbonate of potash. The resulting mass is acted on by water, and the solution being filtered, is evaporated, until, on cooling, it forms a mass of crystals, from which the sulphocyanide may be removed by alcohol, and the mellonide left. It is soluble in water, and yields, by double decomposition with the salts of baryta, lime, &c., mellonides of these bodies, for the most part sparingly soluble.

Urea ($C_2H_4N_2O_2$) may be obtained from urine by adding to it, when concentrated, a strong solution of oxalic acid. The precipitated oxalate of urea is to be boiled with powdered chalk, and the filtered solution concentrated until the urea crystallizes on cooling. It may also be made artificially by adding to a strong solution of cyanate of potash an equal weight of dry sulphate of ammonia; the solution is evaporated to dryness in a water bath, and the urea dissolved out by alcohol. It crystallizes in prisms, very soluble in water, but permanent in the air. At a high temperature it gives off ammonia and cyanate of ammonia, cyanuric acid remaining. Urea contains the elements of cyanate of oxide of ammonium, has neither an acid nor alkaline reaction, is decomposed by hot alkaline solutions, with evolution of ammonia, and, by uniting with two atoms of water, yields carbonate of ammonia, a result which takes place during the putrefaction of urine, the change being brought on by a nitrogenized ferment—the mucus of the bladder. Urea unites with acids, and forms, with nitric and oxalic acids, characteristic salts.

Uric Acid—Lithic Acid ($C_{10}H_4N_4O_6$)—may be obtained from the solid urine of serpents, which, being boiled in solution of caustic potash and filtered, yields uric acid, by the addition of hydrochloric acid, as a white, inodorous, and sparingly soluble powder; soluble without change in sulphuric acid, from which it is precipitated by water. Uric acid also exists in human urine, and appears to be always a product of the action of the animal economy. Of its salts, the urate of soda is interesting; it is the chief ingredient of gouty concretions in the joints, called chalk-stones. The

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How may urea be made artificially? What are its properties? To what substance does it give rise in fermentation? Under what circumstances does uric acid occur? What are chalk-stones?

urate of ammonia occurs as a urinary calculus, and is often deposited from urine as a reddish cloud or powder.

Allantoin ($C_4H_3N_2O_3$) is prepared by boiling uric acid with peroxide of lead; the filtered solution, being concentrated, deposits prismatic crystals of allantoin on cooling. It is soluble in 160 parts of cold water. By a solution of caustic alkali it is decomposed into ammonia and oxalic acid, assuming, during this change, the elements of three atoms of water.

Alloxan ($C_8H_4N_2O_{10}$) is made by the action of concentrated nitric acid on uric acid in the cold. The uric acid is to be added in small portions successively, until about one third the weight of the nitric acid has been used. An effervescence takes place, and there is left a white mass, from which the excess of acid is to be drained. The substance is then to be dissolved in hot water and crystallized. Its solution has an acid reaction and a bitter taste, and stains the skin purple, and, with a protosalt of iron and an alkali, yields a characteristic blue compound.

Alloxanic Acid ($C_4HNO_4 + HO$) may be prepared by decomposing the alloxanate of baryta by dilute sulphuric acid. The alloxanate itself is obtained by the addition of barytic water to a warm solution of alloxan. It is a strong acid, decomposing carbonates, and even water, by the aid of zinc.

Mesoxalic Acid ($C_3O_4 + 2HO$).—Mesoxalic acid may be obtained by boiling a solution of alloxan with acetate of lead, the resulting mesoxalate of lead being decomposed by sulphureted hydrogen. It is a strong acid, resists a boiling heat, and is bibasic.

Mykomelinic Acid ($C_8H_5N_4O_5$) is prepared by boiling a solution of alloxan with an excess of ammonia, and then precipitating by an excess of dilute sulphuric acid. It is a light yellow powder.

Parabanic Acid ($C_6N_2O_4 + 2HO$) is formed by the action of strong nitric acid on alloxan, or uric acid, by the aid of heat. The crystals form on cooling, and may be dried by draining, and then recrystallized. It is soluble in water, reddens litmus, and forms beautiful prismatic crystals.

Under what form does urate of ammonia occur? How may allantoin be prepared? What is the action of cold nitric acid on uric acid? How is alloxanic acid prepared? What substance results from boiling alloxan with acetate of lead? How is mykomelinic acid prepared? What substance results from the action of hot nitric acid on uric acid?

Oxaluric Acid ($C_6H_3N_2O_7 + HO$) may be made by decomposing a hot solution of the oxalurate of ammonia by dilute sulphuric acid, and cooling rapidly. The ammonia salt is itself procured by boiling a solution of the parabanate of ammonia, when it crystallizes, on cooling, in small needles. Oxaluric acid is a white crystalline powder; it contains the elements of one atom of parabanic acid and three of water, and its solution, by boiling, yields oxalic acid and oxalate of urea.

Thionuric Acid ($C_8H_5N_3S_2O_{12} + 2HO$), a bibasic acid prepared by decomposing thionurate of lead with sulphureted hydrogen. It contains the elements of one atom of alloxan, one of ammonia, and two of sulphurous acid.

Uramile ($C_8H_5N_3O_6$).—When an excess of a saturated solution of sulphurous acid in water is mixed with a cold solution of alloxan, and an excess of carbonate of ammonia with caustic ammonia added, and the whole boiled, the thionurate of ammonia is deposited on cooling. From this the lead salt, used in the preparation of the foregoing acid, may be obtained by acetate of lead. The thionurate of ammonia, with a little hydrochloric acid, being boiled in a flask, there separates a white body, which is uramile. It differs from thionuric acid in not containing the elements of two atoms of sulphuric acid. If the thionurate of ammonia is mixed with dilute sulphuric acid and evaporated in a water bath, *Uramilic Acid* is deposited; it is $C_{16}H_{10}N_5O_{15}$.

Alloxantine ($C_8H_5N_2O_{10}$) is made when sulphureted hydrogen gas is passed through a cold solution of alloxan. The product is filtered, washed, and boiled in water, which deposits the alloxantine, on cooling, in transparent rhombic prisms, which turn red on exposure to ammonia. This substance is alloxan, with one atom of hydrogen. A hot solution of it is decomposed when a stream of sulphureted hydrogen is passed through it, and *Dialuric Acid* forms.

Murexide—Purpurate of Ammonia ($C_{12}H_6N_5O_8$)—may be made by the action of dilute nitric acid on uric acid, and then adding ammonia, or by boiling equal weights of uramile and red oxide of mercury with eighty times their weight of water, rendered alkaline by ammonia. The liq-

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What is the relation between oxaluric and parabanic acid? How is uramile prepared? How is alloxantine prepared? What is the action of dilute nitric acid and ammonia on uric acid? What is the color of the crystals of murexide?

uid turns of a deep purple color, and, when filtered, deposits, on cooling, crystals of murexide in square prisms, which, by reflected light, are of a green metallic lustre, and, by transmitted light, of a purple. It is sparingly soluble in cold water, but much more so in hot, and is one of the most splendid compounds known.

Murexan—Purpuric Acid.—Murexide is to be dissolved in a solution of caustic potash, and dilute sulphuric acid added. It forms a yellow powder, and, dissolved in ammonia, gives rise to the foregoing body.

Xanthic Oxide ($C_4H_2N_2O_2$) occurs as a urinary calculus of a brown color and waxy aspect. The calculus may be dissolved in dilute potash, and xanthic oxide precipitates as a white powder by carbonic acid. It is a waxy body.

Cystic Oxide ($C_6H_6NS_2O_4$) occurs also as a urinary calculus.

LECTURE LXXXII.

THE VEGETABLE ACIDS.—*Tartaric Acid, Preparation of.—Salts of Tartaric Acid.—Acids allied to Tartaric.—Citric and its allied Acids.—Malic and its allied Acids.—Tannic Acid.—Gallic Acid.—Acids allied to them.*

OF the vegetable acids several will be described with their associated alkalies. The following are those of which I shall treat in this Lecture:

Tartaric	$C_8H_4O_{10}+2HO.$
Paratartaric	$C_8H_4O_{10}+2HO.$
Pyrotartaric	$C_6H_3O_5+HO.$
Tartralic	$2C_8H_4O_{10}+3HO.$
Tartrelic	$C_8H_4O_{10}+HO.$
Citric	$C_{12}H_5O_{11}+3HO.$
Aconitic	$C_4HO_3+HO.$
Malic	$C_8H_4O+2HO.$
Maleic	$C_8H_2O_6+2HO.$
Fumaric	$C_4HO_3+HO.$
Tannic	$C_{18}H_5O_9+3HO.$
Gallic	C_7HO_3+2HO
Ellagic	$C_7H_2O_4$
Pyrogallic	$C_6H_3O_3$
Metagallic	$C_6H_2O_2$

How may murexan be prepared? Under what circumstances do xanthic oxide and cystic oxide occur?

Besides acids such as these, which constitute a very numerous group, there is another class, which pass under the name of *Coupled Acids*, the peculiarity of which is, that they consist of an acid affixed or coupled to another body, which, without affecting the neutralizing power of the acid, accompanies it in all its combinations. Thus, hyposulphuric acid couples with naphthaline to form hyposulphonaphthalic acid, which neutralizes just as much of any base as hyposulphuric acid could do, the naphthaline not changing its powers.

Tartaric Acid ($C_8H_4O_{10}+2HO$).—A bibasic acid which occurs, as has been already stated, in the juice of grapes and other fruits as bitartrate of potash. It may be obtained by dissolving cream of tartar in boiling water and adding powdered chalk, a tartrate of lime precipitating. The rest of the tartaric acid may be obtained from the solution by the addition of chloride of calcium, which yields another portion of tartrate of lime, which may be decomposed by digesting with an equivalent proportion of dilute sulphuric acid. The concentrated and filtered solution yields crystals acid to the taste, inodorous, and soluble both in water and alcohol; the solution decomposes by keeping. Tartaric acid yields several valuable salts.

Tartrate of Potash—Soluble Tartar ($2KO, C_8H_4O_{10}$) —may be made by adding carbonate of potash to cream of tartar. It is very soluble.

Bitartrate of Potash — Cream of Tartar ($KO, HO, C_8H_4O_{10}$).—This is the salt which is deposited from the juice of the grape during fermentation, as *Argol*. It may be purified from the coloring matter it contains by solution in hot water, and the action of animal charcoal. In cold water it is very sparingly soluble. It yields black flux when ignited in a close vessel, the black flux being carbonate of potash enveloped in carbonaceous matter.

Tartrate of Potash and Soda—Rochelle Salt—Salt of Seignette ($KO, NaO, C_8H_4O_{10}+10HO$)—may be procured by neutralizing a solution of the foregoing salt with carbonate of soda. On evaporation and cooling it separates in large prismatic crystals.

Tartrate of Antimony and Potash — Tartar Emetic

What are coupled acids? From what source is tartaric acid derived? What is soluble tartar? From what source is cream of tartar derived? What is Rochelle salt?

($KOSb_2O_3$, $C_8H_4O_{10}+2HO$).—This valuable medicinal agent is made by boiling oxide of antimony with a solution of cream of tartar; on cooling, the crystals are deposited. They are much more soluble in hot than in cold water, and dissolve without decomposition.

Racemic Acid—Paratartaric Acid.—This remarkable acid, which has the same constitution as tartaric acid, and resembles it very closely, is found in the grapes of certain parts of Germany and France. Racemic acid, however, differs from tartaric in yielding a precipitate with a neutral salt of lime.

Pyrotartaric Acid ($C_6H_3O_5+HO$) is obtained by the destructive distillation of tartaric acid, coming over with a variety of other products.

The action of heat on tartaric acid is remarkable. When exposed to a temperature of 400° F., it melts, throws off water, and yields in succession three different acids, tartralic, tartrelic, and anhydrous tartaric acid, the constitution of which, compared with tartaric acid, is as follows:

Tartaric acid	$C_8H_4O_{10}+2HO$.
Tartralic "	$2C_8H_4O_{10}+3HO$.
Tartrelic "	$C_8H_4O_{10}+HO$.
Anhydrous tartaric	$C_8H_4O_{10}$.

All these, by the continued contact of water, pass back into the condition of tartaric acid.

Citric Acid ($C_{12}H_5O_{11}+3HO$), a tribasic acid, occurring abundantly in the juice of lemons and other sour fruits, and separated therefrom by the aid of chalk and sulphuric acid. It is clarified by digestion with animal charcoal, and yields prismatic crystals of a pleasant taste, and soluble both in hot and cold water. The crystals are of two different forms, according to the conditions of their formation; those which separate in the cold by spontaneous evaporation contain five atoms of water, three of which are basic; but those which are deposited from a hot solution contain only four.

The citrates form a very numerous family of salts, for, as the acid is tribasic, we may have them with three atoms of metallic oxide, or two of oxide and one of water, or one of oxide and two of water, besides subsalts.

Aconitic Acid—Equisetic Acid (C_4HO_3+HO)—is

How is tartar emetic prepared? What is the relation between racemic and tartaric acids? Describe the action of heat on tartaric acid. From what source is citric acid obtained? How many classes of salts does citric acid yield? What substance results from the fusion of citric acid?

formed by fusing citric acid, and the resulting brown product is dissolved in water, the change being

$$C_{12}H_8O_{14} \ldots = \ldots 3(C_4HO_3) + 5(HO),$$

that is, one atom of hydrated citric acid yields three of aconitic acid and five of water. Aconitic acid is remarkable from occurring naturally in the *Aconitum Napellus* and *Equisetum Fluviatile.*

Malic Acid ($C_8H_4O_8 + 2HO$), a bibasic acid, occurring in the juice of apples and other fruits. It may also be prepared from the stalks of rhubarb, in which it occurs with oxalate of potash. It is a colorless solid, soluble in water, the solution changing by keeping. When heated in a retort, it melts, and then boils, emitting a volatile acid, the *Maleic Acid,* $C_8H_2O_6 + 2HO$, which condenses with the water in the receiver; at the same time there forms in the retort crystalline scales of *Fumaric Acid,* $C_4HO_3 + HO$ which may be separated from the unchanged malic acid by solution in cold water. It is to be observed that maleic, fumaric, and aconitic acids are isomeric bodies.

Tannic Acid ($C_{18}H_5O_9 + 3HO$).—An astringent principle found in the bark of the oak, nut-galls, and other vegetable productions. It may be separated by placing in a vessel, *b*, *Fig.* 278, powdered galls. On pouring on them sulphuric ether, a liquid drops through the funnel tube, *c*, into the bottle, *a*, spontaneously separating into two portions; the lower, which is a solution of tannic acid in water, is to be decanted and evaporated in the presence of sulphuric acid in vacuo. It yields tannic acid, or tannin, in the form of an uncrystallized mass. This acid is soluble in water, but much less so in ether, has an astringent taste and reddens litmus paper. With the persalts of iron it yields a characteristic and valuable precipitate of a black color, the basis of common writing ink. It forms insoluble compounds with starch, gelatine, and other organic bodies, that with gelatine being of considerable interest. It is the basis of leather. From the characteristic precipitate it gives

Fig. 278.

From what sources is malic acid derived? What two acids are yielded by it under the action of heat? What is the relation between maleic, fumaric, and aconitic acids? How is tannic acid made? What color does it yield with persalts of iron? What is the basis of leather?

with that metal, it is used as a test for iron, which must, however, be in the state of peroxide, as the protosalts are unacted upon. The gradual darkening of pale writing inks is due to the gradual oxydation of the iron they contain.

Catechin ($C_{15}H_6O_6$).—There is a body extracted by hot water from catechu, called catechin. It crystallizes in needles, and does not form an insoluble compound with gelatine, and gives a green color with persalts of iron. By the action of caustic potash in excess, it yields a black and insoluble substance, *Japonic Acid*. By the action of carbonate of potash, it yields *Rubinic Acid*.

Gallic Acid ($C_7HO_3 + 2HO$) may be formed by exposing a solution of tannic acid to the air, or by making powdered galls into a paste with water, and keeping it exposed in a warm place to the air for some weeks. The mass is then pressed and boiled with water. On cooling, the solution precipitates a quantity of gallic acid, which may be purified by recrystallization. Like tannic acid, this substance yields no precipitate with a protosalt of iron, but a deep blue-black with a persalt. It does not, however, precipitate gelatine. Its crystals are soluble in one hundred parts of cold and three parts of boiling water. The solution has an astringent taste.

Tannic acid passes into gallic acid by oxydation, carbonic acid and water being evolved.

$$C_{18}H_8O_{12} + O_8 \ldots = \ldots 2(C_7HO_3 + 2HO) + 2(HO) + 4(CO_2);$$

that is, one atom of tannic acid and eight of oxygen yield two of gallic acid, two of water, and four of carbonic acid.

Ellagic Acid ($C_7H_2O_4$), or gallic acid minus one atom of water, may be extracted after the removal of gallic acid by an alkali, and precipitated as a gray powder by hydrochloric acid.

Pyrogallic Acid ($C_6H_3O_3$) sublimes when gallic acid is heated in a retort to 420°. It is in the form of white crystals, which are soluble in water. It strikes a black color with the protosalts of iron.

Metagallic Acid ($C_6H_2O_2$) is formed when gallic acid is suddenly heated in a retort to 500°. It is a black mass, insoluble in water, but soluble in alkalies, from which it is precipitated as a black powder by acids.

From what cause do pale writing inks darken? What is catechin? How may gallic acid be prepared? How is ellagic acid procured? What is the action of heat on gallic acid?

LECTURE LXXXIII.

THE VEGETABLE ALKALIES.—*General Properties of Vegetable Alkalies.—Morphia.—Its Preparation and Properties.—Other Alkalies of Opium.—Meconic Acid.—Alkalies of Bark, Quina, Cinchona, &c.—Kinic Acid—Strychnia and Brucia.—Table of Alkaloids.—Artificial Alkaloids.*

THE vegetable alkalies constitute an extensive class of bodies, which are, for the most part, the active medicinal agents of the plants in which they occur. They are generally sparingly soluble in water, but more soluble in boiling alcohol, of a bitter taste, and characterized by containing nitrogen. In their natural state they are united with an acid, and, possessing basic properties in a very marked manner, neutralize acids completely. This quality seems to depend on the nitrogen they contain, and has no reference to their oxygen, for the quantity of this latter element which may be present seems to have no relation to their neutralizing power, and, indeed, in some of them it is not present at all. In many respects they are analogous to ammonia their salts, unlike those of some of the compound radicals, such as ethyle, &c., undergoing decomposition in the same manner as the salts of ammonia. Thus the chloride of ethyle does not decompose the nitrate of silver, but the analogous compounds of ammonia and vegetable alkalies do; and these bodies may therefore be separated from the natural combinations in which they occur precisely as we should separate lime, or potash, or magnesia in their salts. Most of the vegetable alkalies are poisonous bodies, and, indeed, among them we meet with some of the most terrific poisons known. There are several recently-discovered artificial substances, such as *Aniline*, and those containing arsenic and platinum, which ought to be classed with these basic bodies.

Of the numerous vegetable alkalies, those which I shall now describe are the most important.

What are the vegetable alkalies? What element do they all contain? In what condition are they commonly found? What are their relations to acid bodies? What are their general properties? Have any of them been made artificially?

Morphia ($C_{35}H_{20}NO_6 + 2HO$).—This substance is the active principle of opium, and was the first discovered of these alkalies. It was insulated by Sertuerner in 1803. It may be prepared by mixing a concentrated infusion of opium with a solution of chloride of calcium in excess; the mixture, when warmed, deposits a precipitate of meconate and sulphate of lime, and the hydrochlorate of morphia remains in solution. From this it may be crystallized by evaporation, and a dark liquor, containing narcotine and coloring matter, separated by pressure in a piece of flannel. The impure hydrochlorate may be re-dissolved and re-crystallized, and, by repeating the operation, or resorting to animal charcoal, it may be obtained quite white. The salt may now be dissolved in hot water and acted on by an excess of ammonia, which throws down pure morphia as a white precipitate. It may be obtained in crystals by solution in alcohol.

Morphia is almost insoluble in water; it neutralizes acids, and forms crystallizable salts. Its solution is bitter. It dissolves readily in dilute acids, and yields a deep orange-red color when acted on by strong nitric acid. The most common of its salts are the hydrochlorate, the sulphate, and the acetate.

Narcotine ($C_{48}H_{24}NO_{15}$) is associated with morphia in opium. It may be obtained by digesting the insoluble portion with dilute acetic acid; the precipitate produced by ammonia is to be dissolved in alcohol, and purified by animal charcoal. It yields prismatic crystals, insoluble in water, and is a weak base. By the action of peroxide of manganese and sulphuric acid, and by bichloride of platinum, it yields an extensive series of bodies, some of which are acids and others bases.

Codeine ($C_{35}H_{20}NO_5$).—The hydrochlorate of morphia, prepared as above described, contains this base; and when the precipitation with ammonia is made, it remains in solution. When pure, it crystallizes in octahedrons, and is a powerful base. Along with this body, in opium, there occasionally occur other substances of less importance, as ***Thebaine***, *Pseudomorphine*, *Narceine*, and *Meconine*.

Meconic Acid ($C_{14}HO_{11}, 3HO$).—A tribasic acid, asso-

From what is morphia obtained? When was it discovered? Give a process for its preparation. How is narcotine prepared? What are its properties? What other alkaline bodies are obtained from opium?

ciated with morphia in opium. It may be obtained from the meconate of lime, which precipitates in the preparation of morphia by mixing it with warm dilute hydrochloric acid, and repeating the operation until all the lime is removed. When purified from coloring matter, it crystallizes in scales, which are soluble in water and alcohol. When heated, it loses six atoms of water of crystallization; and if its solution be boiled, or the dry acid heated in a retort, *Comenic Acid*, $C_{12}H_2O_8$, $2HO$, a bibasic acid forms with the disengagement of water and carbonic acid. Meconic acid yields, with the persalts of iron, a blood-red solution. It forms several series of salts, like all tribasic acids.

Comenic acid, when heated, yields carbonic acid and a new body, *Pyromeconic Acid*, with a small quantity of another substance, parameconic acid. Pyromeconic acid is composed of $C_{10}H_3O_5$, HO.

Quina—Quinine ($C_{20}H_{12}NO_2$).—This, which is one of the most valuable of the vegetable alkalies, is obtained from *Cinchona Bark*. The decoction of the ground bark in dilute hydrochloric acid is to be boiled in an excess of milk of lime, and the precipitate acted upon by boiling alcohol· on evaporation *Cinchona* is deposited in crystals, but the quina remains in solution. It may be precipitated by the addition of water, and obtained in crystals from the spontaneous evaporation of its solution in absolute alcohol. Quina neutralizes acids perfectly, giving rise to salts, of which the hydrochlorate, phosphate, sulphate, &c., are employed in medicine. It is sparingly soluble in water, but very soluble in alcohol or acids. The basic sulphate of quina, a common preparation, is sparingly soluble in water, but the neutral sulphate is much more so. For this reason, sulphate of quina is often dissolved in dilute sulphuric acid.

Cinchona ($C_{12}H_{12}NO$).—This alkali is obtained, as just stated, in the preparation of quina, with which it is associated in bark, and is found in large quantity both in the gray and red bark. It crystallizes in prisms, is sparingly soluble in water. Its salts, like those of the foregoing, are very bitter.

Two other analogous bodies exist in different species of bark. They are *Chinoidine* and *Aricine*.

How is meconic acid procured? What is the action of heat upon it? What color does meconic acid yield with persalts of iron? When comenic acid is heated, what acids does it yield? From what source is quina derived? How is cinchona prepared? What other alkalies exist in bark?

Kinic Acid ($C_{14}H_{11}O_{11}$, HO) is associated with the foregoing bodies in bark. It is obtained by decomposing the kinate of lime, obtained in the manufacture of sulphate of quina by oxalic acid, filtering the solution from oxalate of lime, and the kinic acid crystallizes on evaporation. It is very soluble in water.

Strychnia ($C_{44}H_{23}N_2O_4$) occurs in *Nux Vomica*, *St. Ignatius's Bean*, in the poison *Upas Tieute*, and other vegetable products. It may be extracted from nux vomica seeds by boiling them in dilute sulphuric acid, and then acting with lime and alcohol as described in the case of quina.

Strychnia requires 7000 parts of water for solution, and communicates to it an intensely bitter taste. It is one of the most violent poisons known. Its alkaline powers are well defined, and it produces a complete series of salts. It is soluble in hot alcohol, but not in ether. The antidote for an over-dose of it is an infusion of tea.

Brucia ($C_{44}H_{25}N_2O_7$) is associated with strychnia, and, being very soluble in cold alcohol, is readily separated from it It is also more soluble in hot water, and possesses the poisonous character of strychnia. These substances are found in union with *Igasuric Acid*.

The following table gives the names of other vegetable alkalies, and bodies analogous to them :

Aconitine.
Antearine.
Asparagine.
Atropine.
Caffeine—Theine.
Chelidonine.
Chinoidine.
Colchicine.
Conine.
Curarine.
Daphnine.
Daturine.
Delphinine.
Elaterine.
Emetine.
Gentianine.
Hesperidine.
Hyosciamine.
Meconine.
Narceine.
Narcotine.
Picrotoxine.
Piperine.
Phloridzine.
Populine.
Salicine.
Solanine.
Stramonine.
Thebaine.
Theobromine.
Veratrine.

Of some of these bodies, as nicotine and conine, it may be remarked that they are volatile oily liquids, which can form crystallizable salts and acids. They both contain nitrogen, and are interesting in their relations to the three following bodies, which may be formed artificially.

With what acids are these bodies associated? From what sources is strychnia procured? What are the properties of strychnia? What is the best antidote to its poisonous effects? With what other alkali is it associated? Mention some other vegetable alkalies? What analogous substances have been formed artificially?

Aniline ($C_{12}H_7N$).—This substance is formed by the action of potash on isatine, and is also one of the ingredients of the oil of coal tar. It is an oily liquid, boils at 358°, and yields crystalline salts with acids.

Leukol ($C_{18}H_8N$).—Formed with the foregoing in oil of coal tar, from which it may be separated by distillation. It is also an oily liquid, and can yield crystallizable salts.

Quinoline ($C_{19}H_8N$).—Formed by distilling quinine or strychnine with caustic potash. An oily liquid, very bitter, strongly alkaline, and yielding crystallizable salts.

Besides these bodies there are other artificial bases of an analogous nature, but which differ in the remarkable particular of containing platinum and arsenic; such, for example, as the platina bases of Reiset and Gros, or the arsenico-platinum radical kakoplatyle. The formation of these organic bases leads us to hope that the vegetable alkalies themselves will hereafter be artificially formed.

LECTURE LXXXIV.

The Coloring Bodies.—*General Properties of Coloring Principles.—Madder.—Hæmatoxyline.—Carthamine.—Yellow Colors.—Chlorophyll.—Indigo.—Sulphindigotic Acid.—Deoxydized Indigo.—Action of Heat and Reagents on Indigo.—Litmus.—Carmine.*

The coloring principles derived from the organic kingdom may be conveniently divided into two classes: the non-nitrogenized and the nitrogenized. They may also be readily classed into groups, as blue, red, yellow, green. For the most part, they are derived from vegetable productions.

For some coloring matters, the fibres of those tissues commonly employed for clothing have a sufficient affinity as to hold the color so that it can not be removed by mere washing, and is permanently dyed. But in other instances this is not the case; the artist then has to avail himself of the qualities possessed by intermediate bodies, such as alumina and the oxide of tin, which at once possess the double quality of an affinity for the coloring matter and an affinity

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What may be remarked as respects the salts of Reiset and Gros? How may coloring principles be classified?

for the cloth fibre. The attraction of these bodies for coloring matter may be illustrated by precipitating alumina in a solution tinged by litmus; the solution becomes perfectly clear, its color going down with the precipitate, and forming with it a lake.

NON-NITROGENIZED COLORING MATTERS.

The *Blue* non-nitrogenized coloring matters are chiefly found in flowers and fruits. They are reddened by acids, and turned green by alkalies.

The *Red* non-nitrogenizing coloring matters are of some importance; among them may be mentioned *Madder Red*, the sublimed crystals of which are known as *Alizarine* ($C_{37}H_{12}O_{10}$). Madder also furnishes a purple and a yellow color.

Hæmatoxyline ($C_{40}H_{17}O_{15}$) is the coloring matter of log-wood; it is soluble in water and alcohol, and furnishes, with iron salts, the black dye for hats. The same principle is yielded by Brazil-wood and cam-wood. *Carthamine* is a very beautiful red, obtained from safflower; it is used for making pink saucers.

The *Yellow* coloring matters. Among these may be mentioned *Quercitrine* ($C_{16}H_3O_9, HO$), derived from the *Quercus Tinctoria; Gamboge*, the dried juice of the *Garcinia Gambogia; Turmeric*, used as a test for alkalies, which turn it brown, from the *Curcuma Longa;* and *Anatto*, from the seeds of the *Bixa Orellana*.

The *Green* coloring matters. *Chlorophyll*, the constitution of which is not known. It is the green coloring matter of leaves. It is insoluble in water, but soluble in alcohol and ether, and is a fatty substance. It is also found, under very interesting circumstances, in the animal system as the coloring matter of bile.

NITROGENIZED COLORING MATTERS.

The nitrogenized coloring matters, among which are some of the most valuable dyes that we possess, may also be divided according to their tint.

Indigo is derived from the juice of several species of Indigofera, and is formed from a colorless or yellow compound

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From what source are the blue non-nitrogenized colors obtained? What is alizarine? What are hæmatoxyline and carthamine? From what sources are quercitrine, gamboge, turmeric, and anatto derived? What is chlorophyll? From what source is indigo derived?

which is dissolved out from the leaves of these plants when they are allowed to ferment with water. A deep blue precipitate (indigo) forms. It appears, therefore, to be a product of oxydation. It comes in commerce in small masses, which, when rubbed, exhibit a coppery aspect, is insoluble in water, alcohol, dilute acids, and alkalies, and may be sublimed, yielding a purple vapor, which condenses into crystals of pure indigo. It dissolves in about fifteen parts of strong sulphuric acid, but still better in Nordhausen oil of vitriol, yielding a mass which is soluble in water. It is *Sulphindigotic Acid.* By contact with deoxydizing agents, blue indigo becomes colorless, as may be shown by digesting powdered indigo, green vitriol, hydrate of lime, and water together. In this state, as in its natural condition, it is soluble in water, and white indigo may be precipitated by hydrochloric acid. On exposure to the air, deoxydized indigo absorbs oxygen rapidly, and becomes blue and insoluble.

When indigo is submitted to destructive distillation, it yields an oily liquid, *Aniline*, possessed of powerfully basic properties, and described in the last Lecture.

The relation which exists between blue and white indigo is seen from their formulas.

Blue indigo . . . . $C_{16}H_5NO_2$.
White indigo . . . . $C_{16}H_6NO_2$.

By several chemists indigo is regarded as containing a radical, *Anyle*, $= C_{16}H_5N$, the symbol for which is *An*. On this view, blue indigo is the anhydrous deutoxide of anyle, AnO_2, and white indigo the hydrated protoxide, AnO, HO.

Under the action of heat and of reagents, indigo yields an extensive class of bodies, to which much attention has been given. In this place I can do little more than enumerate some of them. With dilute nitric acid it yields *Anilic* or *Indigotic Acid.* With strong nitric acid it yields *Picric* or *Carbazotic Acid,* a substance of a yellow color, bitter taste, and forming explosive salts. Heated with bichromate of potash, sulphuric acid, and water, it yields *Isatine*, which crystallizes in red prismatic crystals, and contains the elements of blue indigo, with two additional atoms of oxygen. This body, under the influence of an alkaline

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How is sulphindigotic acid made? What is deoxydized indigo? How is aniline made? What is the relation between blue and white indigo What is anyle? What are indigotic acid, carbazotic acid, and isatine?

solution, unites with one atom of water, and changes into *Isatinic Acid.* Under the influence of chlorine, isatine yields *Chlorisatine,* by an atom of chlorine substituting one of its hydrogen atoms, and *Bichlorisatine,* by the substitution of two chlorine atoms for two hydrogen ones; and these, again, as in the case of isatine itself, acted upon by alkaline solutions, yield each an acid. Caustic alkalies, acting on indigo, yield *Crysanilic* and *Anthranilic Acids.*

Litmus is derived from the *Rocella Tinctoria, Lecanora Tartarea,* &c. These lichens yield to ether a crystalline substance, to which the name *Lecanorine* is given. It does not contain nitrogen. It is in white crystals, soluble in hot alcohol and ether. This substance, heated with baryta or alkalies, yields *Orcine,* by losing two atoms of carbonic acid. Orcine crystallizes in prisms, which have a yellowish tint and a sweet taste. Mixed with ammonia, and exposed to the air, oxygen is absorbed, and the liquid assumes a deep purple tint. From this acetic acid precipitates a deep-red powder, *Orceine,* $C_{16}H_9NO_7$, which contains nitrogen, and is supposed to be the basis of the dye-stuff of litmus. With alkalies it gives a blue color. Litmus is extensively used in chemistry as a test for acids and alkalies.

Carmine is the coloring matter of the cochineal insect, *Coccus Cacti.* The coloring matter may be obtained from the insect by water or ammonia. The carmine of commerce is a lake containing alumina.

Aloes is the inspissated juice of certain species of *Aloe,* used as a purgative medicine. When heated with nitric acid, and water added, a yellow precipitate is thrown down, which, when purified, is *Chrysammic Acid.* It yields yellow crystals of a bitter taste, and furnishes a solution of a purple color. Its salts are crystallizable, by transmitted light of a red color, with a green metallic reflection like murexide. The liquid from which this acid was precipitated contains picric acid.

What is the effect of alkaline solutions on isatine? What is the effect of chlorine upon it? From what sources is litmus derived? What are orcine and orceine? From what source is carmine derived? How is chrysammic acid prepared?

LECTURE LXXXV.

THE FATTY BODIES.—*Properties of the Saponifiable Fats.—Distinction between Fixed and Volatile Oils.—Preparation of Soaps.—Stearine and Stearic Acid.—Margarine and Margaric Acid.—Oleine and Oleic Acid.—Margarone.—Production of Glycerine.—Natural Oils, as Palm Oil, Cocoa Tallow, and Nutmeg Butter.—Spermaceti.—Cholesterine.—Three Classes of Volatile Oils.—The Camphors.*

THIS class of substances is characterized by several well-marked peculiarities, and may be conveniently divided into two natural groups, oils and fats. They belong both to the vegetable and animal systems. In the former they usually abound in the seeds or fruits; in the latter they are deposited in the cellular structure of the adipose tissue. The natural fats are usually mixtures of two or more ingredients, which differ from one another in consistency. In most instances they are stearine and margarine, along with a liquid oleine. These oils can not be distilled without undergoing decomposition; exposed to the air, they gradually absorb oxygen and evolve carbonic acid. Many of them, in which this change takes place with rapidity, turn into resinous bodies; and hence their application, in the art of painting, as drying oils. When acted upon by alkalies, the fixed oils and fats give rise to soaps, and hence are spoken of as *Saponifiable*.

Oily bodies may be divided into fixed and volatile. The fixed oils decompose when heated; the volatile ones distill. A simple test, therefore, is sufficient to distinguish them. When a few drops of an oily substance are put on paper, if it be a volatile oil it soon evaporates, and leaves the paper without a stain; if fixed, the paper remains greasy The fixed oils have but little odor, the volatile oils commonly a characteristic one. They are all insoluble in water;

Into what natural groups may the fatty bodies be divided? What are the natural fats? What change do the drying oils undergo? How may the fixed oils be distinguished from the volatile? What is the difference of their properties?

many of them are soluble in alcohol; but in ether they are freely dissolved.

By exposure to a low temperature the constituent principles of a mixed oil may often be separated from each other, the more solid substances separating as the temperature descends. When olive oil is thus treated, an exposure of 40° F. causes a deposit of *Margarine:* the fluid portion which is left is *Oleine.* Animal fats exposed to pressure between folds of blotting paper communicate to it oleine, and the solid residue which is left behind is a mixture of margarine and *Stearine.* When the fixed fats are boiled with alkaline solutions, *Soaps* are formed; these substances, which are of extensive use in domestic economy and the arts from their detergent qualities, are freely soluble in water. In the process of making them, the fats undergo a change; they form true acids, stearine yielding stearic acid, margarine margaric acid, and oleine oleic acid, which may be set free by decomposing the soap with an acid. With them there is also formed a sweet substance, *Glycerine,* which appears to be the same, whatever fat may have been originally employed. Of the varieties of soap met with in commerce, *Soft Soap* is made from potash, combined with whale or seal oil; *Hard White Soap* from tallow and caustic soda; *Hard Yellow Soap* from soda, tallow, palm oil, and resin. In the preparation of white soap the alkaline solution is made to boil, and tallow added in small portions until no more can be saponified; the solution now contains soap and free glycerine; the former is separated by the addition of common salt, in a solution of which it is insoluble. It floats on the top of the liquid. It is then run into moulds, and cut into bars for commerce. In this process the manufacturer does not add so much salt as to separate all the water. Commercial soap still contains from 40 to 50 per cent.

Stearine may be obtained from purified mutton fat by suffering a warm ethereal solution to cool. The stearine crystallizes, and margarine and oleine are left in solution. A repetition of the process purifies it. It is a white body, insoluble in water and in cold alcohol. It melts at 130°. When saponified, it yields glycerine and stearic acid.

What is the effect of a reduction of temperature on mixed oils? Into what may olive oil be thus decomposed? What are soaps? How may the different varieties be formed? How is stearine prepared, and what are its properties?

Stearic Acid ($C_{68}H_{66}O_6$) may be crystallized from a hot alcoholic solution, is insoluble in water, and without taste or smell. It is soluble both in alcohol and ether, melts at 158°, and may be volatilized without change.

Margarine.—This substance remains with oleine in the ethereal solution arising in the preparation of stearine, and may be obtained from it by evaporation and pressing the soft mass in paper. Margarine is found more abundantly in human than in other kinds of fat.

Margaric Acid ($C_{68}H_{66}O_6$) is prepared by saponifying margarine with potash and decomposing with hydrochloric acid. It is also formed with other products by the distillation of stearic acid. It crystallizes in white needles, its melting point being 140°.

Oleine.—When almond or rape oil is dissolved in ether and the solution exposed to a low temperature, the margarine crystallizes, and oleine may be obtained by evaporating the ether. It remains liquid at a temperature of 0°. From it *Oleic Acid* ($C_{44}H_{39}O_4$) may be obtained by saponification and decomposition with muriatic acid, as in the foregoing instances. Its melting point is about 20°. It gives rise to a class of salts.

Margarone ($C_{66}H_{66}O_2$).—When a mixture of margaric acid and lime is distilled, this substance is formed, and carbonic acid separates. It is a white solid, like spermaceti, and melts at 170°.

Glycerine ($C_6H_8O_6$).—This substance arises when any fatty matter is saponified with potash, the soap being decomposed with tartaric acid, and dissolving the glycerine out by alcohol. It is a colorless liquid, specific gravity 1·26; it is soluble in water and alcohol, but not in ether. It may be cooled to a very low point without assuming the solid form. When mixed with sulphuric acid, the two bodies unite directly, and *Sulphoglyceric Acid* is the result: an acid having many analogies with sulphovinic.

Palm Oil is brought from Africa, and much of it used in the manufacture of yellow soap. It is of a reddish-yellow color, and contains, besides oleine, a solid fat, *Palmitine.* It is insoluble in water, slightly soluble in hot alcohol, but

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What is the process for preparing stearic acid? How are margarine and margaric acid obtained? What are the properties of oleine? How is oleic acid made? What is margarone? Under what circumstances does glycerine form? What are palm oil and palmitine?

very soluble in ether. Its melting point is 118°. By saponification and decomposition with an acid, it yields *Palmitic Acid*, the melting point of which is 140°. It is a bibasic acid.

Cocoa Tallow.—A solid fat obtained from the cocoa-nut, and used in the manufacture of candles. Its oleine and stearine may be separated by pressure, or by boiling alcohol, from which the stearine crystallizes on cooling.

Among other fatty substances and allied bodies may be mentioned *Nutmeg Butter*, which yields, among other products, *Myristicine*, and by saponification, *Myristic Acid*. *Elaidine*, which arises from the action of nitrous acid on oleine; it furnishes, by the common process, *Elaidic Acid*. *Suberic Acid*, which arises from the action of nitric acid on cork. *Succinic Acid*, by the destructive distillation of amber, or by the continued action of nitric on stearic acid *Sebacic Acid*, by the destructive distillation of oleic acid. *Butyrine*, *Caproine*, and *Caprine*, which are contained in butter. These yield, by saponification and decomposition, *Butyric*, *Caproic*, and *Capric Acids*. Butyric acid can be made, as we have seen, artificially by fermentation. *Bees' Wax* is a mixture of two bodies: *Cerine*, which may be dissolved by boiling alcohol, and *Myricine*, which is insoluble therein. *Spermaceti*, which is obtained from certain species of whales, yields, under the process for glycerine, a substance, *Ethal*, and this, under the action of hot potash, gives *Ethalic Acid*, with evolution of hydrogen gas. *Cholesterine* is obtained from biliary calculi; it also occurs in the substance of the brain.

THE VOLATILE OILS.—These, for the most part, are found in plants, or are derived from them by simple processes Many of them are extensively used in the arts in the manufacture of varnishes, and others in the preparation of perfumery. Their solutions in alcohol form *Essences*, and in water *Medicated Waters*. They are commonly obtained by the distillation of those parts of the plants in which they occur, with water, and consist of two substances, a solid portion, *Stearopten*, or camphor, and a true oil. They may be divided into groups according to their constitution.

What is palmitic acid? Mention some other bodies belonging to the same class. From what are suberic, succinic, and sebacic acids derived? What bodies are contained in butter, and what acids do they yield? What two substances are found in bees' wax? From what are spermaceti and cholesterine derived?

Volatile Oils containing Carbon and Hydrogen.

Turpentine.
Citron.
Copaiva.
Storax.
Bergamotte.
Cubebs,
&c.

Volatile Oils containing Carbon, Hydrogen, and Oxygen.

Cajeput.
Lavender.
Rosemary.
Peppermint.
Pennyroyal.
Valerian.
Spearmint,
&c.

Volatile Oils containing Sulphur.

Black mustard.
Horseradish.
Onions.
Asafœtida.

The stearoptens (camphors) of the volatile oils are best represented by common camphor, which is extracted from the *Laurus* and *Dryabalonops Camphora* by distilling with water. It is a white, tough, semitransparent mass, lighter than water, of a well-marked odor, melts at 350°, and soon after sublimes rapidly unchanged. *Artificial Camphor* is made by passing dry muriatic acid gas into oil of turpentine. It is a muriate of oil of turpentine. The true camphors originate in several different ways; sometimes by the oxydation of the oils from which they are derived; sometimes they are hydrates of those oils; and sometimes they are isomeric with them.

LECTURE LXXXVI.

THE RESINS, BALSAMS, AND BODIES ARISING IN DESTRUCTIVE DISTILLATION.—*Colophony, Gum Lac, Amber, &c.* —*India-rubber.*—BALSAMS.—*Products of the Destructive Distillation of Wood.—Paraffine, Eupione, Creasote, and allied Bodies.—The Destructive Distillation of Coal.—Naphthaline, Paranapthaline, Kyanol, Carbolic Acid.—Products of slow Decay.—Ulmine and Ulmic Acid.—Crenic and Apocrenic Acid.—The Varieties of Coal and other subsidiary Bodies.*

THE resins are bodies in many respects analogous to the camphors, but are distinguished from them by the circumstance that they are not volatile without decomposition. In many instances they act as acids; they all contain oxygen.

Into what groups may the volatile oils be divided? What are the camphors? What is common and artificial camphor? What are the resins?

Colophony is a mixed resin, obtained by the distillation of turpentine with water, the oil of turpentine passing over It is a mixture of two resins, *Pinic* and *Sylvic Acids*, which may be separated by cold alcohol, in which sylvic acid is insoluble.

Gum Lac, which is one of the resins, occurs under three forms: shell lac, stick lac, and seed lac. It is used in the preparation of lacquers, and is the chief ingredient in sealing-wax. Among other resins may be mentioned *Copal, Mastic, Dragon's Blood, Gamboge, Sandarac*, and *Dammara Resin.*

Amber is a substance belonging to this class. It is formed in beds of bituminous wood, and often incloses insects in a state of beautiful preservation. Its specific gravity is about 1·07. By distillation it yields succinic acid.

Caoutchouc—Indian-rubber, or Gum-elastic—is the product of the *Jatropa Elastica*, the *Hævea Caoutchouc*, and several other tropical trees. The milky juice which they yield is dried on moulds of various forms; it turns of a black color by being smoked. From its imperviousness to water, this substance has of late been introduced for a great variety of purposes. It is combustible, burns with a bright flame, is softened by boiling water, and still more so by ether. In ether, as also in naphtha and coal oil, it may be dissolved. Bags of it, soaked in ether until they become gelatinous, may be distended, by blowing into them, to a very great size, and thus become useful for a variety of purposes. Very few chemical agents act upon India-rubber: it is extensively used for connecting the parts of chemical apparatus.

Balsams are compounds of resins with volatile oils; some of them also contain benzoic or cinnamic acids. Some, as benzoin, are solid; and others, as the *Balsams* of *Tolu* and *Peru*, are viscid fluids.

THE PRODUCTS OF THE DESTRUCTIVE DISTILLATION OF WOOD, &c.

When wood is submitted to distillation in close vessels, a black, inflammable liquid called *Tar* is formed; it contains

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What substances may be obtained from colophony? What is gum lac? What acid does amber yield by distillation? From what sources is India rubber derived? What is the cause of its black color? How may it be softened, and in what dissolved? What are the balsams? What are tar and pitch?

a great many remarkable bodies, among which the following may be mentioned. The solid black residue which is left after the distillation or inspissation of tar constitutes *Pitch*.

Paraffine ($C.H$) is obtained by distilling tar, several oils coming over: it is from the heaviest that this substance is extracted. It is a solid substance, lighter than water, of a fatty appearance; it melts at 111° F., and distills unchanged. Few chemical agents act upon it: it remains unchanged by the alkalies, acids, &c., but is soluble in turpentine and naphtha. From its chemical indifference it has obtained its name (*Parum Affinis*).

Eupione (C_5H_6) occurs abundantly in animal tar, from which it may be prepared by distillation, and subsequently purified by rectification from sulphuric acid. From paraffine it may be separated by exposure to cold, or, being more volatile, by distillation. It is a colorless liquid, specific gravity ·074; it boils at 339° F. It is insoluble in water, but very soluble in alcohol.

Creasote is extracted from the heavy oil of tar by a complicated process. It is an oily, colorless liquid, of a burning taste, exhaling a powerful odor of wood smoke. It is slightly heavier than water, boils at 400° F., is combustible. One hundred parts of water dissolve about 1¼ of this substance, and obtain its peculiar odor. It has the remarkable property of coagulating albumen and preserving flesh from putrefactive changes. From this latter circumstance its name is derived.

Among allied substances may be mentioned *Picamar*, an oily liquid of a bitter taste, which boils at 518° F., and combines with bases to form crystalline compounds. *Kapnomar*, a colorless liquid, having an odor of rum; boils at 360° F., and forms, with oil of vitriol, a purple solution. *Cedriret*, which forms red crystals, giving, with creasote, a purple solution, and with sulphuric acid a blue. *Pittakal*, a dark blue solid, which yields blue precipitates with metallic salts. It contains nitrogen.

When coal tar is submitted to distillation, like wood tar, it yields a volatile oil, which, by being submitted to rectification, becomes *Coal Oil*, or *Artificial Naphtha*. From it

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What properties distinguish paraffine? What are the properties of eupione? What remarkable properties does creasote possess? From what is its name derived? From what sources are picamar, kapnomar, cedriret, and pittakal obtained?

a variety of substances may be extracted; they either preexist in the oil, or are formed by the operation.

NAPHTHALINE ($C_{10}H_4$) is obtained by rectifying coal gas tar; it forms colorless or crystalline plates, melting at 136° F., and boiling at 413° F. It exhales a peculiar odor, is very combustible, insoluble in water, but soluble in ether and alcohol; the specific gravity of its vapor is 4·528. It dissolves in sulphuric acid, and the solution, on being diluted with water and saturated with carbonate of baryta, yields two salts, one containing *Sulphonaphthalic Acid*, and the other an acid less known.

Paranaphthaline ($C_{15}H_6$) is associated with naphthaline, but differs from it by being insoluble in alcohol, by which liquid they may therefore be separated.

Kyanol ($C_{12}H_7N$), an oily liquid, which, though volatile, has a boiling point of 358° F. It is heavier than water, with which it may be combined, and is soluble in alcohol and ether. It possesses basic properties, and yields several well-defined salts.

Carbolic Acid—Hydrate of Phenyle ($C_{12}H_5O$)—is found in that portion of oil of tar which boils between 300° F. and 400° F. This, being agitated with potash, and the result decomposed by an acid, yields carbolic acid, which may be purified by rectification from caustic potash. It is an oily liquid, but may be obtained in long, needle-shaped crystals. A splinter of pine-wood first dipped in it and then in strong nitric acid becomes of a blue color, which then passes into a brown. In many particulars this substance resembles creasote so closely, that a supposition has been entertained that they are in reality the same body.

When woody matter is gradually decomposed by contact with air and moisture, *Ulmine* and *Ulmic Acid* are produced. They arise from a partial oxydation, attended by the production of carbonic acid and water, the action being orginally occasioned by azotized matter in the wood; corrosive sublimate, or any other body which possesses the quality of checking ferment action, may therefore be resorted to to prevent the dry-rot of wood. When the access of air is for the most part cut off, the brown bodies, ulmine and

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What are the properties of naphthaline? What substance closely resembles it? What are the properties of kyanol? What substance does carbolic acid closely resemble? Under wha circumstances are ulmine and ulmic acid produced? What bodies may be employed to prevent dry-rot ulmic acid, no longer appear alone, but with them many other substances, of the family of the hydrocarbons, arise. Besides these, as in the formation of vegetable soil and turf, azotized acids, such as the *Crenic* and *Apocrenic*, appear. These originate in the decay of the nitrogenized constituents of the wood, an action which probably precedes its general disorganization. They are often found in mineral springs, in combination with oxide of iron, forming ochery stains. Crenic acid, by exposure to the air, changes into *Apocrenic Acid*, a substance much less soluble in water.

There is abundant proof that all the varieties of coal have originated from woody fibre. For the production of these, it seems requisite that the wood should be immersed in water at a moderately high temperature, and without free contact of air. The ulmine bodies form from the decay of wood at the surface of the earth; the coal bodies under a heavy pressure. Of these we have many varieties, differing much in constitution: *Lignite*, which is of a brown color, and in which the structure of the wood is more or less perfectly preserved; the various forms of *Bituminous Coal*, as cannel coal, Newcastle coal, &c.; *Anthracite*, which contains but little hydrogen.

With these more valuable natural products are frequently found small quantities of others of less importance, as *Ozocherit*, or fossil wax; *Idrialine*, which is isomeric with oil of turpentine; *Petroleum*, or *Naphtha*, which in many Eastern countries is collected in wells. It arises, probably, from the decomposition of coal by the action of the natural heat of the earth.

LECTURE LXXXVII.

ANIMAL CHEMISTRY.—*Equilibrium of the System.—Causes of Diminution and Increase.—Relation of Oxygen to the Food.—Digestion, the Nature of it.—Description of the Process.—Artificial Digestion.—Two great Varieties of Food.—Nutrition in the Carnivora and Graminivora.—Routes of the Passage of Nutritious Matter into the System.*

IN the preceding Lectures I have given the descriptive

From what bodies do crenic and apocrenic acids arise? What is the source of the different varieties of coal? What is lignite?

history of many of the more important organic compounds, and chiefly those belonging to, or derived from, the vegetable kingdom. It remains now to mention another class which seems to bear a closer relation to animal beings. The appearance and destruction of these compounds lead by ready steps to a consideration of the physiological functions of the animal mechanism.

There are certain causes which tend constantly to change the weight of an adult, healthy individual; causes of increase and causes of diminution. Among the former may be mentioned food, drinks, and atmospheric air; among the latter, urine, fæces, transpired and expired matters. And these, in the course of a year, amount to many hundred pounds; yet the resulting action of the mechanism is such that, at the end of that time, the weight remains unchanged.

This fact, the constancy of adult weight, can, therefore, only be explained by an examination of the action of the matters introduced into the interior of the system on each other, or an examination of the matters rendered. Whatever is fit for food, when burned in the open air, with free access of oxygen, must yield carbonic acid, water, and ammonia; and these, in point of fact, are the results of the action of the animal mechanism. Oxygen gas, introduced by the respiratory process through the lungs, effects eventually the destruction of the hydrocarbons and nitrogenized bodies which have been introduced through the stomach; and carbonic acid, ammonia, and the vapor of water, or substances in a transition state, which tend eventually to assume those forms, are the result. An elevated temperature must, as a consequence, be obtained.

Before the introduction of chemical principles into the science of physiology, it was a favorite idea that the animal system possessed the peculiarity of resisting the influence of external agents. This is an error. There is no essential difference between the physical effects taking place in the body during life and after death, nor is there any principle of resistance to external agents possessed by living structures. The only distinction is, that during life the effete materials pass off by appointed routes—the kidneys, the

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What causes are in operation tending to change the weight of an adult animal? Mention some of the causes of increase and some of diminution. What is the chemical nature of the food?

lungs, or the skin; and after death, these passages being closed, they accumulate in the interior of the body.

The matters returned by an animal to the external world are all found to be oxydized bodies, or such as arise from processes of oxydation. The result is, therefore, forced upon us that the primitive action of the mechanism is the oxydation of the food in the system by air which has been introduced through the lungs

The process of digestion appears to be exclusively for the object of effecting the minute subdivision of the food. By the action of the teeth or other organs of mastication, it is first roughly divided and simultaneously mixed with saliva. It is then passed into the stomach, and in that organ mixes with the gastric juice, a viscid and slightly acid body. This mixture is perfected by certain movements which the food now undergoes, and under the conjoint action of the saliva and the gastric juice it is totally broken up into a gray, semifluid, homogeneous mass, sometimes acid and sometimes insipid, of the consistency of cream or gruel, called *Chyme.* This gradually passes out through the pyloric orifice of the stomach, and enters the intestine.

It has been a question whether artificial digestion could be performed, but it now appears to be universally admitted that an acidulated water, containing animal matter in a state of change, has the power of impressing analogous changes on organized substances submitted to its action, just as the gastric juice, containing hydrochloric or acetic acid, with animal matter undergoing metamorphosis, derived from the saliva or the coats of the stomach, possesses the power of dissolving fibrin or coagulated albumen.

Soon after its entrance into the intestine the chyme is mingled with bile and pancreatic juice, the former coming from the liver, the latter from the pancreas. The effect appears to be a division of the chyme into three parts: 1st. A creamy fluid; 2d. A whey-like fluid; 3d. A red sediment: the two former, commingled, constitute what is designated *the Chyle.*

What gas is introduced through the lungs? How do these act on each other? Do animal structures possess any power of resisting the influence of external agents? Why do we conclude that the oxydation of the food is the principal effect going on in the system? What is the object of digestion? How is chyme prepared? Can digestion be conducted artificially? With what fluids does the chyme mingle? What is their action on it? What is chyle?

It has been already remarked that the aim of the digestive process appears to be the subdivision of the food. It is for this that the teeth comminute it; and the gastric juice, excited to activity by the oxygen introduced with the saliva, breaks down by its ferment action all albuminous and fibrinous matters, and prepares the food, in this condition of extreme subdivision, for its passage into the blood-vessels.

Before we can trace the changes which then occur, it is proper, however, to remark that, as respects the food itself, it may be distinguished into two varieties: 1st. The food of nutrition, or the nitrogenized food; 2d. The food of respiration, or the non-nitrogenized food.

The nutritive processes of carnivorous animals are very simple; they live on the graminivora, and find, in the carcases they consume, the fats, the fibrin, and other such bodies which are necessary for their own economy; these, therefore, simply require to be brought into a state of solution, or of extreme subdivision, and then are absorbed into the blood-vessels. In these cases the fats constitute the food of respiration, and the nitrogenized bodies that of nutrition.

But the graminivora find in the vegetable matters they use the same essential principles; their fibrin, albumen, and fats are directly obtained from plants, in which they naturally occur. In the digestive process of the two great classes of animals, there is not therefore, in reality, any difference; both find in their food the elements they require

There is reason for believing that the two classes of food are introduced into the system by different routes—the fatty or respiratory food passing through the lacteals, and the nitrogenized bodies being taken up by the veins.

What two great varieties of food are there? Describe the nutritive processes of the carnivora. What is their respiratory food? Describe the nutritive processes of the graminivora. By what routes are the two varieties of food introduced into the system?

LECTURE LXXXVIII.

ORIGIN AND DEPOSITS OF THE FATS AND NEUTRAL NITROGENIZED BODIES.—*Artificial Formation of Fat.—It may be made in the Animal System, or directly absorbed from the Food.—Proofs of the latter.—Varieties of Fat arising in partial Oxydation.—Changes in Fat as it passes through the Systems of the Graminivora and Carnivora.—Its final Destruction.—Origin and Deposit of the Neutral Nitrogenized Bodies.—Properties of Fibrin, Albumen, Casein, Protein, Gelatin, &c.*

Two opinions have been entertained respecting the origin of the fat which occurs in the adipose tissues of animals. 1st. It has been supposed to be *produced* by processes taking effect in the system ; or, 2d. Simply collected from the food.

In many various processes fatty bodies arise. Thus, when flesh meat is left in a stream of water, a mass of *adipocere* is eventually found. During the action of nitric acid on fibrin, and in the preparation of oxalic acid from starch, oily bodies are apparently produced. There is every reason to believe, however, that these are rather insulated than formed, or that they pre-exist in the bodies from which they are apparently derived.

But recent experiments, as in the preparation of butyric acid from sugar, have decisively demonstrated that the fatty bodies can be artificially formed from the non-nitrogenized by processes such as those of fermentation, and, consequently, we have every reason to suppose that the animal system can form fats from the food, although none might occur there naturally.

But, though the power of forming oily from amylaceous bodies may be possessed by the animal mechanism, there can be no doubt that in many instances it is not resorted to, and that fats contained in the food are at once absorbed into the system. Often this absorption takes place with so slight

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What opinions have been held respecting the origin of fat? In what processes is it apparently produced? What reason is there to believe that it can be formed from the starch bodies? What reason is there for believing that many fats are directly absorbed into the system?

a change impressed upon the oil, that without difficulty we can detect its presence by its odor or its taste. Thus the milk of cows which are fed on linseed cake tastes strongly of that substance; and at those seasons of the year when such animals feed on young shoots or leaves containing odoriferous oils, the taste is at once detected in the milk.

The deposition of fat upon an animal, and the production of butter in its milk, bear a certain relation to the amount of oleaginous matters found in its food. For this reason, Indian corn, which contains from eight to twelve per cent. of oil, furnishes one of the most available articles for feeding and fattening cattle. It is now, however, admitted, that where foods without fat are used, the system possesses the power of effecting their production; thus bees will produce wax though fed upon pure sugar, and animals will grow fat though fed on potatoes alone.

A great number of the fatty bodies may be derived from margaric acid by processes of partial oxydation. With a limited supply of oxygen gas, ethalic and myristic first make their appearance; and the supply being still continued, there follow cocinic, lauric, &c., the process being as shown in the following table:

Margaric.
Ethalic.
Myristic.
Cocinic.
Lauric.
Capric.
Œnanthytic.
Caproic.
Valerianic.
Butyric.

These partial oxydations being perfected, there result at last carbonic acid gas and water, the same bodies which appear when a fat is directly burned in the open atmospheric air.

The fats which occur in plants pass into the systems of graminivorous animals, and there undergo changes, a series of partial oxydations occurring. It is only a part which is completely destroyed so as to produce carbonic acid and water, and this part is the element of respiration. The residue accumulates in the cells of the adipose tissues, and, devoured by the carnivorous tribes, is destined to undergo in them those successive changes which bring it back to the

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Is there any relation between the production of butter and the quantity of oil in the food? Can bees form wax from sugar? By what process can the fatty bodies be derived from each other? In what do these partial oxydations terminate at last? What change occurs to vegetable fats in passing through the systems of the graminivora? What is the object of the entire combustion of a portion of it? By what means is the residue at last brought to the same state?

condition of carbonic acid and water, and restore it to the atmosphere from which it was originally derived by plants.

The amylaceous bodies and fats, or the non-nitrogenized bodies, are, therefore, the food of respiration; their office is to neutralize the oxygen introduced by the lungs, and, by the production of carbonic acid gas and water, keep up the temperature of the animal system

I have already described the fatty bodies, and given the history of their general properties. It is unnecessary to repeat here what has been already said.

When the expressed juices of plants, such as beets, turnips, &c., are allowed to stand, there is deposited, after a short time, a coagulum or clot, which does not appear to differ in any respect from animal *Fibrin*. If this be removed, and the temperature of the juice raised to 212° F., it becomes turbid again, from the deposit of a second body, *Albumen*. On separating this and slowly evaporating, a film forms on the surface, identical with *Casein*. These three bodies contain nitrogen, and may, therefore, be looked upon as the representatives of the neutral nitrogenized class.

Fibrin ($C_{48}H_{36}O_{14}N_6 . + (S.P)$).—This substance may be obtained by beating fresh-drawn blood with twigs, and washing with water and ether the clot which adheres thereto. As thus prepared, fibrin is a white, elastic body, insoluble in water, alcohol, or ether, but soluble in hydrochloric acid, with which it yields a blue solution. It possesses the power of decomposing rapidly the deutoxide of hydrogen. When dried it shrinks very much in volume, but, for the most part, recovers its bulk when again moistened. Fibrin derived from arterial and venous blood is not altogether the same; the latter may be dissolved in a warm solution of nitrate of potash, but the former can not. In the formula annexed to this body, the symbols within the brackets merely mean small and indeterminate quantities of sulphur and phosphorus.

Albumen occurs abundantly in the serum of blood and in the white of eggs, from which it may be obtained by neutralizing in a solution of it the associated soda with acetic acid, and on dilution with cold water it falls as a white precipitate, soluble in water containing a minute quantity of

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What bodies constitute the food of respiration? What is the composition of fibrin? From what sources may it be derived? What are its properties? What are the sources and properties of albumen?

alkali. Exposed to a sufficient heat, common albumen coagulates and becomes a white body, wholly insoluble in water. The strong acids also unite directly with it, and form insoluble compounds; acetic and the tribasic phosphoric acid are exceptions. With metallic salts, as corrosive sublimate, it gives insoluble precipitates; hence its use as an antidote for that poison. Its constitution is identical with that of fibrin, except that it appears to contain twice as much sulphur.

Casein is found abundantly in milk. It is insoluble in water, but, like albumen, is readily dissolved if free alkali is present. It may be obtained by coagulating milk with sulphuric acid, and dissolving the curd, after it has been well washed with water, in a solution of carbonate of soda. By standing it separates into two portions, oily and watery. From the latter the casein is re-precipitated by sulphuric acid, and the process repeated. The casein is finally washed with ether to remove any trace of fat. It is a white substance, soluble in an alkaline water, the solution not being coagulated by boiling, but a skin forms on the surface as evaporation goes on. It can, however, be coagulated by certain animal membranes, as by the interior coat of the stomach of a calf. It contains five or six per cent. of bone earth.

The foregoing bodies are sometimes spoken of as the **Protein** group, from the circumstance, as is shown in their formula, that they all contain $C_{48}H_{36}O_{14}N_6$, a body which passes under the designation of protein. It may be extracted from them by dissolving either of them in an alkaline solution, and precipitating by an acid. It is a tasteless, white, insoluble body, soluble in acetic acid and in alkalies. It yields a binoxide and tritoxide, which may be produced by boiling fibrin in water in contact with air These substances are the chief constituents of the *buffy* coat of inflammatory blood.

Gelatin ($C_{13}H_{10}N_2O_5$) is prepared by dissolving isinglass in warm water. It forms, on cooling, a soft jelly, which contracts as it dries. Solution of gelatin is precipitated by corrosive sublimate, tannic acid, or infusion of galls; with the latter bodies it yields a precipitate which is the basis of leather. Glue is an impure gelatin.

What are the sources and properties of casein? What is protein? What relation has it to the foregoing bodies? What oxides does it give? How is gelatin obtained? What precipitate does it give with infusion of galls?

On examining the constitution of some of the leading tissues of the animal system, it is plain that they bear a remarkable relation to protein, as is shown in the following table:

Protein, $C_{48}H_{36}N_6O_1$ . . . . $= Pr.$
Arterial membrane . . . . . $= Pr + HO.$
Chondrin (rib cartilage) . . . $= Pr + HO + O.$
Hair, horns . . . . $= Pr + NH_3 + O_3.$
Gelatinous tissues . . . . . $= 2Pr + 3NH_3 + HO + O_7$

These different bodies are therefore derived from the protein group by processes of partial oxydation, for in their constitution they correspond to oxides, hydrated oxides, &c.

The nitrogenized bodies introduced into the system pass through the same changes as the non-nitrogenized: partial oxydations giving rise to various tissue forms, and ending in perfect oxydation, with a production of water, ammonia, and carbonic acid.

Whether we regard the respiratory or the nutritive food, we see that the result is the same. Introduced through the blood-vessels into the system, it is brought under the destructive influence of oxygen arriving through the lungs, and, as I have already explained, the amount of oxygen is so adjusted to the amount of these classes of food combined, that in an adult and healthy individual the weight does not change, even after the lapse of a considerable period of time.

LECTURE LXXXIX.

OF THE INTRODUCTION OF RESPIRATORY AND NUTRITIOUS FOOD INTO THE BLOOD, AND ITS TRANSMISSION THROUGH THE SYSTEM.—*Absorption by the Lacteals and Veins.—Cause of the Circulation of the Blood.—Constitution and Properties of the Blood.—Plasma and Disks.—The Offices of each.—The Coagulation of Blood.—Analysis of Blood.*

THE ordinary principles of capillary attraction are amply sufficient to account for the absorption of nutritious matter from the intestinal cavity, both by the lacteal vessels and

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What relation does protein bear to other tissues? What changes do the nitrogenized bodies pass through? What physical principle is involved in the absorbent action of the lacteals and veins?

the veins By this it is eventually brought into the general current of the circulation, and distributed to every part of the system.

With respect to the forces involved in the circulation of the blood, most physiologists have regarded the hydraulic action of the heart as amply sufficient to account for all the phenomena. It is now on all hands conceded that this organ discharges a very subsidiary duty. The whole vegetable creation, in which circulatory movements of liquids are actively carried on without any such central mechanism of impulsion; the numberless existing acardiac beings belonging to the animal world; the accomplishment of the systematic circulation of fishes without a heart; and the occurrence in the highest tribes, as in man, of special circulations which are isolated from the greater one, have all served to demonstrate that we must look to other principles for the cause of these remarkable movements.

The cause of the circulation of the blood is to be found in the chemical relations of that liquid to the tissues with which it is brought in contact. On the principles of capillary attraction, a liquid will readily flow through a porous body for which it has a chemical affinity, but it will refuse to flow through it if it has no affinity for it. On this principle we can easily explain why the arterial blood presses the venous before it in the systemic circulation, and why the reverse ensues in the pulmonary. This explanation of the circulation of the blood, which I offered some years ago, is now admitted by many of the leading physiological writers to be true.

The systemic circulation takes place because arterial blood has a high affinity for the tissues, and venous blood little or none. The pulmonary circulation takes place because venous blood has a high affinity for atmospheric oxygen, which it finds on the air cells of the lungs, and arterial blood little or none. On the same principle we may explain the rise of sap in trees, the circulatory movements in the different animal tribes, and the minor circulations of the human system.

The most striking peculiarity of the blood is the incessant

What reasons are there for supposing that the action of the heart is not the only cause of the circulation? What explanation may be given of the circulation in the capillaries? What is the cause of the systemic circulation? What of the pulmonary?.

change which it undergoes. It is constantly being destroyed, and as constantly being reproduced. It consists of two portions, the *Plasma*, a clear fluid, of a yellowish tinge, which contains fibrin, albumen, and fat; and in this there float disk-like bodies of different shapes and magnitudes in different animals. In man they are about $\frac{1}{4000}$th of an inch in diameter, consist of a sac of *Globulin*, a body of the protein family, and in the interior they contain a red substance, *Hæmatin*, which gives them their peculiar color. On one portion of them there is a nucleus or speck, consisting of coagulated fibrin. When the disks are old and about to be destroyed, their interior is filled with *Hæmaphein*, a yellow substance, corresponding to the coloring matter of the urine. Besides these, there are lymph, chyle, and oil globules in the blood.

A continuous metamorphosis goes on during the circulation of the blood; the plasma serves for the purposes of nutrition, the disks for the production of heat. They absorb oxygen in the air cells of the lungs, and transmit it to all parts of the system; and as they grow old and disappear, new ones are formed from the plasma.

Although fibrin is known to exist in plants, I doubt very much whether it is directly absorbed *as Fibrin* into the system. Besides the direct proof which we have from the analysis of these bodies, we know that fibrin and albumen so closely resemble each other in constitution that they are mutually convertible into each other. During the hatching of an egg from its albumen the flesh (fibrin) of the young chicken is formed, a phenomenon accompanying the absorption of oxygen from the air. In the human system, abundant observation has proved that there is a direct connection between the quantity of oxygen introduced through the lungs and the amount of fibrin in the blood. When the respiratory process is unduly active, the disks oxydize with rapidity, and the amount of fibrin increases; but when the reverse takes place, there is a restraint on the change of the disks, and the amount of fibrin declines.

The coagulation of the blood is a phenomenon which has excited much attention, physiologists generally looking upon

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Of what parts is the blood composed? What are the properties of the plasma? Of what are the disks composed? What are globulin, hæmatin, and hæmaphein? What are the functions of the plasma and disks respectively? What reasons are there for supposing that fibrin may be made in the system from albumen or casein?

it either as wholly inexplicable, or what, in reality, amounts to the same thing, as due to the death of the blood. What connection there is between its life and fluidity, is not so very apparent A little reflection will, I am persuaded, deprive this phenomenon of much of its fictitious importance, since it is plain that the coagulation of the blood, or, in other words, the separation of fibrin from it takes place in the body as well as out of it, for from this coagulated fibrin the muscular tissues are formed, and from it their waste is repaired. By passing through two capillary circulations, the systemic and the pulmonary, the rapidity of the process is very much interfered with; but still, it eventually takes place.

I here insert one of Lecanu's analyses of the blood; it may serve to give an idea of the constitution of that liquid. It must not be forgotten, however, that such analyses, beyond mere general results, are of little value; the composition of the blood varies incessantly in the same individual. For instance, the mere accident of his being thirsty, or having recently drank abundantly of water, will make an entire change in the analysis of the blood.

Water	780·145.
Fibrin	2·100.
Coloring matter	133·000.
Albumen	65·090.
Crystalline fatty matter	2·430.
Oily matter	1·310.
Extractive matter	1·790.
Salts and loss	149·35.
	1000·000.

The following represents the constitution of hæmatosin:

Carbon	66·49.
Hydrogen	5·30.
Nitrogen	10·50.
Oxygen	11·05.
Iron	6·66.
	100·00.

Does the coagulation of the blood take place during life? Of what are the muscular tissues composed? What circumstances tend to change the constitution of the blood?

LECTURE XC.

Nature of the Processes of Secretion.—*Origin of Secretions.—Phenomena of Respiration.—Arterialization.—Production of Animal Heat.—Removal of effete Matters.—Constitution of Milk.—Uses of that Secretion.—Mucus.—Pus.—Bile.—Urine.—Calculi.—Bones.—Nervous Matter.*

During the starvation of an animal all its various secretions are still formed; a consideration which proves that the production of urine, bile, and other such bodies is, in reality, connected with the destructive processes going on in the animal system. These processes of decay originate in the action of oxygen admitted by the process of respiration.

The lungs, which constitute the organ by which air is introduced, are originally developed as diverticula from the œsophagus, and finally become an immense congeries of cells emptying into the trachea. In respiration they are perfectly passive, the air being introduced and expelled alternately by muscular contraction. It is commonly estimated that, on an average, about 17 inspirations are made each minute, and at each inspiration about 17 cubic inches of air are introduced.

The blood presents itself on the air cells of a deep blue color, and is then known as venous blood. Through the thin wall of the cell it obtains oxygen from the air, and gives out carbonic acid. It is the coloring matter of the disks which discharges this function, and during the act of change its tint alters to a bright crimson. It is said now to be arterialized, or to constitute arterial blood. The magnitude of the scale on which this operation is carried forward may be appreciated from the circumstance that in a man of average size, in a single day, about seven tons of blood have been exposed to 226 cubic feet of atmospheric air.

The oxygen thus introduced acts directly either on the tis-

How is it known that the secretions arise from destructive processes? What is the structure of the lungs? How many inspirations does a man make, on an average, in a minute? How many cubic inches of air are introduced at each inspiration? What is meant by the arterialization of the blood? What action does the oxygen introduced exert?

sues themselves, as it is distributed by the systemic circulation, or on the elements of respiration they contain. In the latter case, carbonic acid gas and water are the result; in the former, carbonic acid, water, and ammonia. But these changes can not take place without an elevation of temperature. Carbon and hydrogen can neither burn in the air nor in the animal system without evolving heat. The high temperature which an animal can maintain is therefore directly proportional to the quantity of oxygen it consumes.

The tissues being thus acted upon, give rise, during their metamorphoses, to new products, which require to be removed from the system; these, passing under the name of secretions, are discharged by glands or other special organs. Thus the carbonic acid, for the most part, escapes from the lungs; the ammonia through the kidneys; the water through both those organs and the skin. Liebig has attempted to show that if the elements of urine be added to the elements of bile, they will represent the elements in the blood; and there can be no doubt that the sulphates and phosphates found in the urine arise directly from the sulphur and phosphorus previously existing in the muscular fibre and nervous matter.

As an illustration of the principles here given in relation to the functions of nutrition and secretion, the constitution and properties of milk may be cited. The following is an analysis of it:

Water	873·00.
Butter	30·00.
Casein	48·20.
Milk sugar	43·90.
Phosphate of lime	2·31.
" " magnesia	·42.
" " iron	·07.
Chloride of potassium	1·44.
" " sodium	·24.
Soda in combination with casein	·42.
	1000·000.

Of the substances here mentioned, all are undoubtedly obtained directly from the food. In the herbage on which a graminivorous, milk-giving animal feeds, every one of

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In what does animal heat arise? Through what channels are the leading secretions, water, ammonia, and carbonic acid, discharged? What supposed relation is there between the constituent of the urine and bile conjointly and those of the blood? From what do the sulphates and phosphates of the urine arise? What are the chief constituents of milk? From what source are they derived?

these constituents occurs. I have already shown that the butter, or fat, and the casein are thus directly derived, and the evidence is equally complete that all the salts of phosphoric acid and chlorine arise from the same source.

A young animal, which, in the first periods of its life, is nourished exclusively on milk, finds in that milk all the various compounds it requires for its own existence and growth. The respiratory food is there—it is the butter and milk sugar; the nitrogenized food is there—it is the casein; and we have already seen that albumen and casein are both convertible into fibrin; the casein, thus, in the mother's milk, becomes converted into flesh in the young animal. To insure the growth of its bones, phosphate of lime (bone earth) is present; there is also chlorine to form the hydrochloric acid of its gastric juice, and soda, which is an essential ingredient in its bile.

It remains now to add a brief description of the properties of the remaining leading animal substances, among which may be mentioned:

CHYLE is usually of a white or reddish-white tint. It resembles blood in constitution and power of coagulating. It contains much fat, which gives to it a cream-like aspect.

MUCUS exudes from the surface of mucous membranes. It is of a white or yellow color, of a viscid constitution, and insoluble in water. It dissolves in a solution of potash, and is precipitated by an alkali.

PUS, a secretion from injured surfaces, resembling mucus in many respects, but distinguished by not being soluble in potash solution, but converted by it into a gelatinous body, which can be pulled out in threads.

BILE, a yellow liquid, secreted by the liver from the portal blood; it turns green in the air, has a bitter taste and an alkaline reaction, due to the presence of soda. Its coloring matter is chlorophyl. It is regarded as a choleate of soda, the constitution of choleic acid bieng $C_{76}H_{66}N_2O_{22}$. Of the correctness of this formula there is considerable doubt, since it has been recently affirmed that *Taurine*, which is a derivative body, contains a large amount of sulphur.

What becomes of the butter, milk sugar, casein, phosphate of lime, chlorine, and soda in the body of the young animal? What is chyle? What is mucus? How may pus be distinguished from mucus? What are the chief properties of bile? From what is it formed? What does taurine contain?

Urine, a yellow-colored fluid, secreted by the kidneys; has an acid reaction; its specific gravity from 1·005 to 1·030; putrefies at a moderate temperature, its urea passing into the condition of carbonate of ammonia. The chief constituents of urine are urea, uric acid, the sulphates and phosphates of potash, soda, lime, ammonia, and a yellow coloring matter, with mucus of the bladder.

The constitution of the urine changes in disease. In *Diabetes* it contains grape sugar, as may be shown by the test of sulphate of copper, already mentioned. Diabetic urine may even be fermented with yeast, and alcohol distilled from it.

Urinary Calculi are stony concretions often formed in the bladder of man and many animals; they are of different kinds: 1st. Uric acid. 2d. Urate of ammonia. 3d. Phosphate of lime, magnesia, and ammonia. 4th. Oxalate of lime, or mulberry calculus. 5th. Cystic and xanthic oxides.

Bones consist of two parts, an animal and an earthy matter. The latter is the phosphate of lime (bone earth).

Nervous Matter consists of an albuminous substance with several fatty principles, distinguished by the remarkable fact that they contain phosphorus. In addition, it contains cholesterine.

It would not agree with the object of these Lectures were I here to offer any detailed remarks on the functions of the brain and the nervous system. Of the action of the lungs, the liver, the kidneys, or other such organs, we are beginning to have a very distinct idea; but it is altogether different with the functions of the cerebro-spinal axis; there every thing is in mystery and darkness; yet it is in what may be hereafter discovered in relation to the action of this system that our chief hopes of the advance of animal chemistry and physiology depend.

What are the chief constituents of urine? How may sugar be detected in diabetic urine? What varieties of urinary calculi are there? Of what are bones composed? What are the chief constituents of nervous matter

INDEX.

THE END.

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